

AD-A101 076

WASHINGTON UNIV SEATTLE DEPT OF OCEANOGRAPHY  
CURRENT RESEARCH ACTIVITIES OF THE DEPARTMENT OF OCEANOGRAPHY, (U)

F/0 8/10

APR 81

N00014-75-C-0502

UNCLASSIFIED REF-A81-3

ML

For  
All  
201076



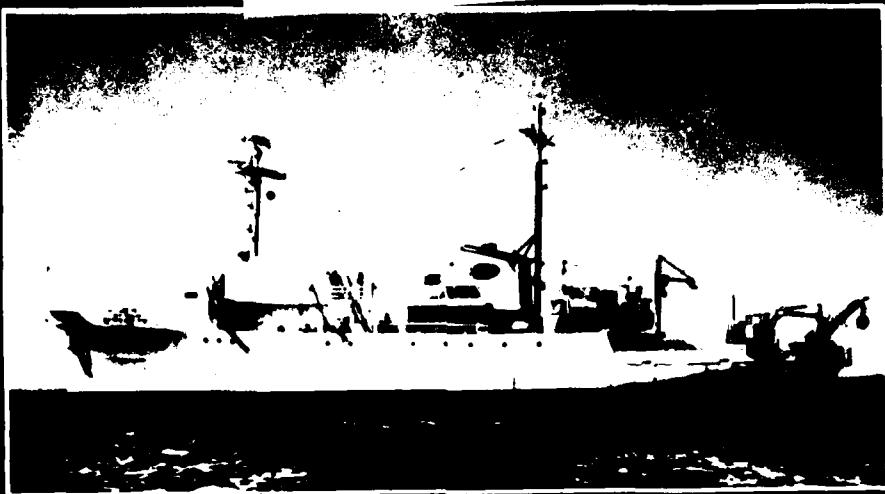
END  
DATE  
FILED  
7-81  
DTIC

DMC FILE COPY

ADA101076

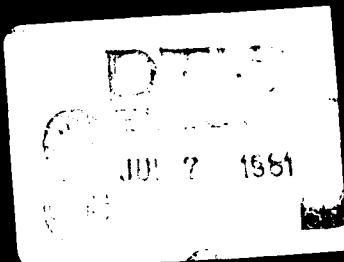
LEVEL III

①



Current  
Research  
Activities

Department  
of Oceanography



DISTRIBUTION STATEMENT A  
Approved for public release;  
Distribution Unlimited

University  
of Washington  
Seattle 1981

815 04163

CURRENT RESEARCH ACTIVITIES  
OF THE  
DEPARTMENT OF OCEANOGRAPHY

University of Washington  
Seattle, Washington 98195

N00014-75-C-0502

Reference: A81-3

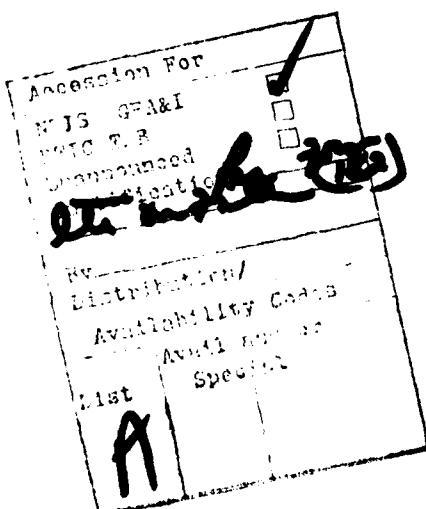
April 1981

## TABLE OF CONTENTS

INTRODUCTION.....	i
MARINE OPERATIONS.....	iii
<i>R/V Thompson</i> 1979 cruise tracks.....	iv
<i>R/V Thompson</i> 1980 cruise tracks.....	v
 BIOLOGICAL OCEANOGRAPHY.....	1
Mechanisms of transfer of energy and biomass in coastal marine ecosystems of the Pacific Northwest.....	1
Phytoplankton studies.....	1
Zooplankton studies.....	2
Chlorophyll degradation products.....	3
Sensitivity analysis of a model of phytoplankton growth.....	4
Benthos studies.....	4
Surf-zone studies.....	5
Relationship between nitrate uptake and growth in marine phytoplankton..	6
Nanoplankton studies.....	6
Respiration and intrinsic growth rates of ciliated protozoans and very small metazoans.....	7
Production control mechanisms of the subarctic Pacific Ocean.....	7
Subarctic Pacific ecosystem research: a planning project.....	8
Relative abundance of copepod species in temperate-boreal pelagic communities.....	8
Selective predation by cyclopoid copepods.....	9
Distribution and abundance of zooplankton in the Columbia River Estuary.....	9
Population dynamics and feeding of larvaceans.....	9
Effects of UV-B radiation on near-surface zooplankton.....	10
Biomagnetic studies.....	10
Flux of organic particulates to the sea floor.....	10
Benthic organism-sediment-flow interactions.....	11
Role of predation in soft-bottom benthic succession.....	12
Community development on submerged artificial surfaces.....	12
 CHEMICAL, BIO-, AND GEOCHEMICAL OCEANOGRAPHY	
Comparative studies of enzymes involved in ammonia-N assimilation in marine phytoplankton.....	14
Chemical parameters and microbial populations in organic matter diagenesis in anoxic marine environments.....	14
Hydrocarbons in Puget Sound.....	15
Chemical and geochemical studies off the Washington Coast.....	16
Sediment-trap studies.....	16
Sedimentological studies.....	17
Carbon fluxes in Lake Washington.....	17
Effect of redox reactions on marine chemistry.....	18
Diagenesis in marine sediments.....	18
Manganese nodule program.....	18
Diagenesis and diffusion in interstitial waters.....	18
Adsorption experiments.....	19
Composition of marine humic substances.....	19
Lignin geochemistry of quaternary sediment cores.....	20

<b>GEOLOGICAL AND GEOPHYSICAL OCEANOGRAPHY</b>	
Sediment transport in the Columbia River Estuary.....	21
Sediment transport in the nearshore environment.....	21
Joint U.S/China investigation of marine sediment dynamics.....	22
A Pacific Northwest paleomagnetic instrumentation consortium.....	22
Paleomagnetic, rock magnetic, and oblique mineralogy studies in an eastern Iceland drill core.....	22
Paleomagnetic input into dynamo models for the earth's magnetic field..	23
Rock magnetism of Pacific Ocean deep-sea cores.....	23
Thermal state of old oceanic crust and lithosphere.....	23
Convection in a porous medium at high Rayleigh number and its geothermal implications.....	24
DSRV Alvin in situ investigation of deep oceanic crust.....	25
Volcanic volatiles.....	25
Fine structure of the oceanic crust.....	25
Generation and evolution of the oceanic crust.....	25
Hot spot-ridge crest-fracture zone dynamics.....	26
ONR refraction experiment.....	26
Seismic properties of the upper Iceland crust.....	26
Puget Sound Lowland seismic activity.....	27
<b>PHYSICAL OCEANOGRAPHY</b>	
Model studies of the ocean-atmosphere system.....	28
Basic model studies of steady oceanic circulation.....	28
Energy-balanced global climate model.....	28
Large-scale oceanic thermal dynamics.....	28
Predictability of the atmosphere.....	28
Studies of finite amplitude waves.....	29
Geostrophic transport and water characteristics of the central Pacific Equatorial Current system.....	29
Dynamics of equatorial waters.....	29
Arctic sea-air interaction.....	30
Bering Sea ice studies.....	30
International Southern Ocean Studies.....	30
Diagnostic determination of low frequency currents in the Southern Ocean.....	31
Dynamic analysis of the eddy field.....	31
Arctic Ocean circulation studies.....	32
Polar Basin.....	32
West Spitsbergen Current.....	32
Beaufort Sea.....	33
Oceanic variability and dynamics.....	33
Oceanic fronts in the western North Pacific.....	34
Oceanic boundary layers.....	35
Mixing processes.....	35
Eastern Boundary Current systems.....	36
Statistical theoretical methods in ocean dynamics.....	36
Internal wave studies.....	37
Hydrodynamics of amplitude-modulated water waves.....	37
Mid-ocean acoustic transmission experiment.....	38
Effect of continental shelves on tides.....	38
Nonlinear generation of long-period tides on continental shelves.....	39

Transport of dissolved and suspended matter in the Washington-Oregon coastal zone.....	39
Transport of particulate suspended matter through submarine canyons.....	40
Mixing in highly stratified estuaries.....	40
Turbulent boundary layer studies.....	40
Analysis of circulation contributions to upstream salt flux.....	41
Computation of periodic tidal motions in deep estuaries and fjords.....	41
 APPLIED OCEANOGRAPHY	
Processes and resources of the Bering Sea Shelf.....	43
Physical oceanographic studies in outer Bristol Bay.....	43
Early life history studies of Alaska pollock.....	43
Outer continental shelf environmental assessment program.....	43
Norton Sound/Chukchi Sea oceanographic processes.....	43
Under-ice current and pressure measurements in Norton Sound.....	44
Bristol Bay oceanographic processes.....	44
Bering/Chukchi seas acoustic studies.....	44
Deep-ocean mining environmental study.....	44
Dissolved components of discharge.....	45
Increased oxygen demand and microbial biomass.....	45
Effect of deep-sea mining on marine phytoplankton and primary productivity.....	46
Impact of a pilot-scale manganese nodule mining test on the benthic community.....	46
Prediction of oil slick motion in coastal waters.....	46
Effects of an oil well blowout on zooplankton.....	47
Collaborative acoustic analyses.....	47
Suspended sediment study.....	47
Stability of dredge materials in Elliott Bay.....	47
Tribal fish ticket software system.....	47
FACULTY AND STAFF.....	48
DEGREES AWARDED IN 1979-80.....	52
CONTRIBUTIONS.....	54
INDEX TO CONTRIBUTORS TO CURRENT RESEARCH ACTIVITIES.....	68



## INTRODUCTION

The University of Washington's Department of Oceanography has established comprehensive teaching and research programs, which are conducted by a diverse group of faculty, staff, students, and support personnel. More than 120 projects comprise our research program, which covers a broad range of oceanographic investigations and has annual expenditures in excess of eight million dollars. These investigations range from individual research projects to multidisciplinary and/or multiuniversity projects, such as the Deep Ocean Mining Environmental Study (DOMES), the first GARP Global Experiment (FGGE), the First International Biomass Experiment (FIBEX), the Global Atlantic Tropical Experiment (GATE), the International Program of Ocean Drilling (IPOD) supported by the Deep Sea Drilling Project (DSDP), the International Southern Ocean Studies (ISOS), the Manganese Nodule Program (MANOP), the Outer Continental Shelf Environmental Assessment Program (OCSEAP), the Joint U.S.-U.S.S.R. Mid Ocean Dynamics Experiment (POLYMODE), the Processes and Resources of the Bering Sea Shelf Program (PROBES), the Rivera Ocean Seismic Experiment (ROSE), and the proposed Subarctic Pacific Ecosystem Research Program (SUPER).

The Department is supported primarily by funds from the State of Washington and federal agencies. The major sources of funding during 1979-80 were the National Science Foundation (49%), State of Washington (14%), National Oceanic and Atmospheric Administration (13%), Office of Naval Research (9%), and the Department of Energy (9%). The remaining support was derived from the U.S. Army Corps of Engineers, U.S. Air Force, various state and local government agencies, and from private organizations.

The research program provides substantial support for teaching via a large assortment of facilities and projects that are available for undergraduate and graduate student research. In 1979-80, 17 students achieved the Ph.D. degree, and 19 Master of Science and 60 Bachelor's degrees were awarded.

Both the educational and research aspects of the department are augmented through joint or adjunct appointments of personnel with the Applied Physics Laboratory, the Applied Mathematics Program, the Geophysics Program, the Atmospheric Sciences Department, the Department of Geological Sciences, the College of Fisheries, the Division of Marine Resources, the Quaternary Research Center, and the Institute for Marine Studies. Several research projects are being carried out in collaboration with departments in addition to those listed above, e.g., the Friday Harbor Laboratories, and the Departments of Chemistry, Aeronautics and Astronautics, Zoology, and Environmental Health.

Additional research opportunities for the department are provided by associations with the Pacific Marine Environmental Laboratory of NOAA and the U.S. Geological Survey. Several PMEL and USGS personnel are affiliate faculty members, and numerous joint research projects are being conducted. Cooperative arrangements with other governmental agencies, i.e., the National Marine Fisheries Service, the National Ocean Survey, the U.S. Coast Guard, the U.S. Navy, the U.S. Army Corps of Engineers, and the Washington State Department of Ecology also extend the research opportunities.

The Departments of Oceanography and Atmospheric Sciences continue participation in the Joint Institute

for Study of the Atmosphere and Ocean (JISAQ), which was established in 1977, through appointment of senior fellows and visitors at all levels. Collaboration on ocean climate research, estuarine research and marine chemistry has resulted in a steady stream of senior and post-doctoral visitors who add a great deal to our research and education program.

Recent additions to the faculty include Affiliate Professor William I. Aron, Director, Northwest and Alaska Fisheries Center, Adjunct Professor Minze Stuiver, Geological Sciences and Zoology, and Research Associates Cho-Teng Liu, Ronnal Reichard, and Stephen Riser, joint appointments with JISAQ, and Eric D'Asaro and Brady Elliott, joint appointments with the Applied Physics Laboratory.

Several major research journals are edited by departmental faculty. Dr. F.A. Richards is the editor of *Deep-Sea Research* and Dr. D.P. Henry is a member of the editorial board. Dr. M. C. Gregg is associate editor of the *Journal of Physical Oceanography*, and Dr. B.A. Taft is associate editor of the *Journal of Marine Research*. Dr. K. Banse is on the editorial board of the *Plankton Society of Japan* and is an editorial advisor for the *Marine Ecology-Progress Series*. Drs R.T. Merrill and B.T.R. Lewis are associate editors of the *Journal of Geophysical*

*Research*. Dr. D.A. McManus is editor of *Marine Geology*. Dr. R.W. Sternberg is on the editorial board of *Geological Marine Letters* and associate editor of the *Journal of Sedimentary Petrology*, and Dr. J.S. Creager is co-editor of *Quaternary Research* and associate editor of *Marine Geology*. Dr. Lewis is editorial advisor for marine geology on JOIDES Site Surveys. Dr. Merrill edited a special volume of *Physics of the Earth and Planetary Interiors*, and Dr. Sternberg was a contributing editor to a lecture notes series, *Coastal and Estuarine Marine Studies* (Springer-Verlag).

Well-equipped teaching and research laboratories are augmented by a research fleet consisting of the 209-foot general oceanographic research vessel, the *Thomas G. Thompson*, two 65-foot vessels, the *Hoh* and the *Onar*, and various small craft (see also page iii).

Summaries of the projects currenting being carried out in the Department of Oceanography are provided. The faculty, staff, and students associated with each research project are identified at the end of the project summary; square brackets indicate the students who participated in the research. Inquiries may be addressed to the faculty members or to the Associate Chairman for Research.

## MARINE OPERATIONS

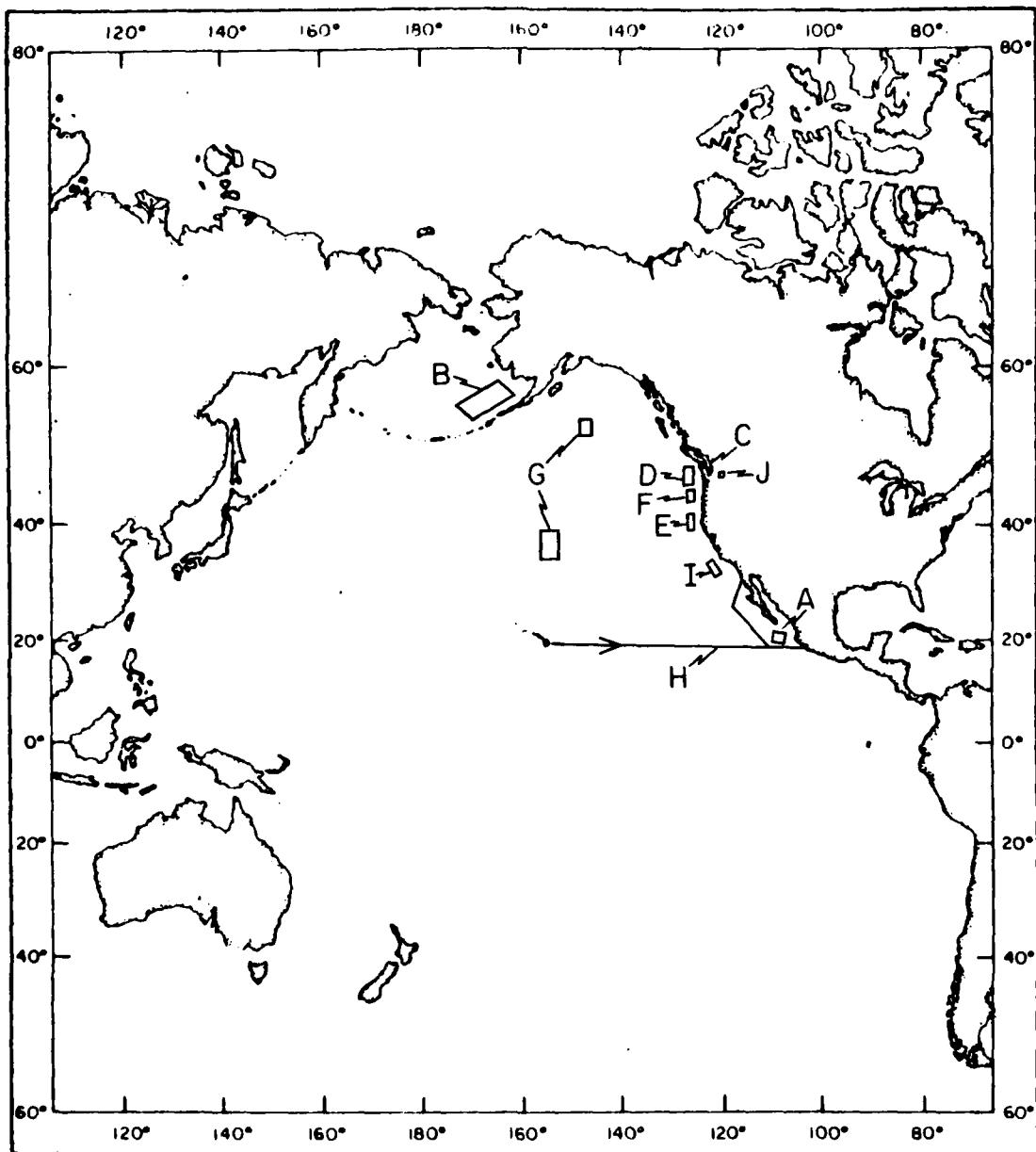
In 1979, the R/V *Thomas G. Thompson* commenced the field season with an extended cruise, January through March, off the coast of Mexico. This was the ROSE (Rivera Ocean Seismic Experiment) project, a multi-institutional effort, jointly sponsored by the Office of Naval Research and the National Science Foundation. In late March, *Thompson* returned to the Bering Sea for the second year of the PROBES (Processes and Resources of the Bering Sea Shelf) program. This program is a multidisciplinary, multi-institutional ecosystem investigation. Upon return from Alaskan waters in July, the ship cruised to Saanich Inlet, B.C. for a seven-day chemistry cruise, "Redox Reactions"; then off the coast of Washington for two weeks on a biological cruise, jointly sponsored by the Department of Energy, the National Science Foundation, and Battelle Northwest. In early August, the *Thompson* proceeded to the northern California coast for a two-week geological investigation, "Sediment Accumulation" and "Bettis Low Level Ocean Waste Disposal." Enroute home to Seattle, in mid-August, a physical oceanography program, "Sediment Transport," was conducted off the Oregon and Washington coasts. In late August a return trip was made to Saanich Inlet for the second phase of the chemistry cruise. After a brief respite in Seattle, the *Thompson* sailed in early September to the northeast central Pacific on another biological cruise, then to the Mexican coast for a chemistry cruise. Proceeding up the coast in early November, a biological investigation was conducted in the Southern California Bight area. The field season was completed in late

November with a two-day geology cruise into Lake Washington.

The 1980 field season for R/V *Thompson* got off to a late start because of required shipyard repairs; the first cruise was a four-day trip off the coast of Washington for a seismic experiment in late February. On 10 March, *Thompson* sailed for the Bering Sea to again take up the PROBES program. Enroute home from Alaska, a biological investigation was conducted at Ocean Station PAPA and in the north central gyre area north of Hawaii. After a short stay in port in July, two programs, seismic and dredging, were conducted in the Juan de Fuca Ridge area off the Washington Coast. These programs spanned the July 22 through August 30 time period. On 11 September, the ship sailed from Seattle for an extended cruise into the South Pacific, which will terminate in 1981. The first leg of this voyage was a chemical investigation along a track from Monterey, California, to Hawaii; then south along the 160th meridian to 20° south, ending at Tahiti in late October. The second leg was another chemical cruise which proceeded eastward from Tahiti to the East Pacific Rise area, then back to Tahiti. On the final leg for 1980, *Thompson* conducted a biological investigation along a track from Tahiti to Hawaii.

The R/V *Hoh* and R/V *Onar* were engaged throughout 1979 and 1980 in short cruises in Puget Sound, several trips to British Columbia: Saanich Inlet, the Fraser River area of and Knight Inlet. These cruises covered a wide spectrum of biological, chemical, geological, and physical oceanography projects.

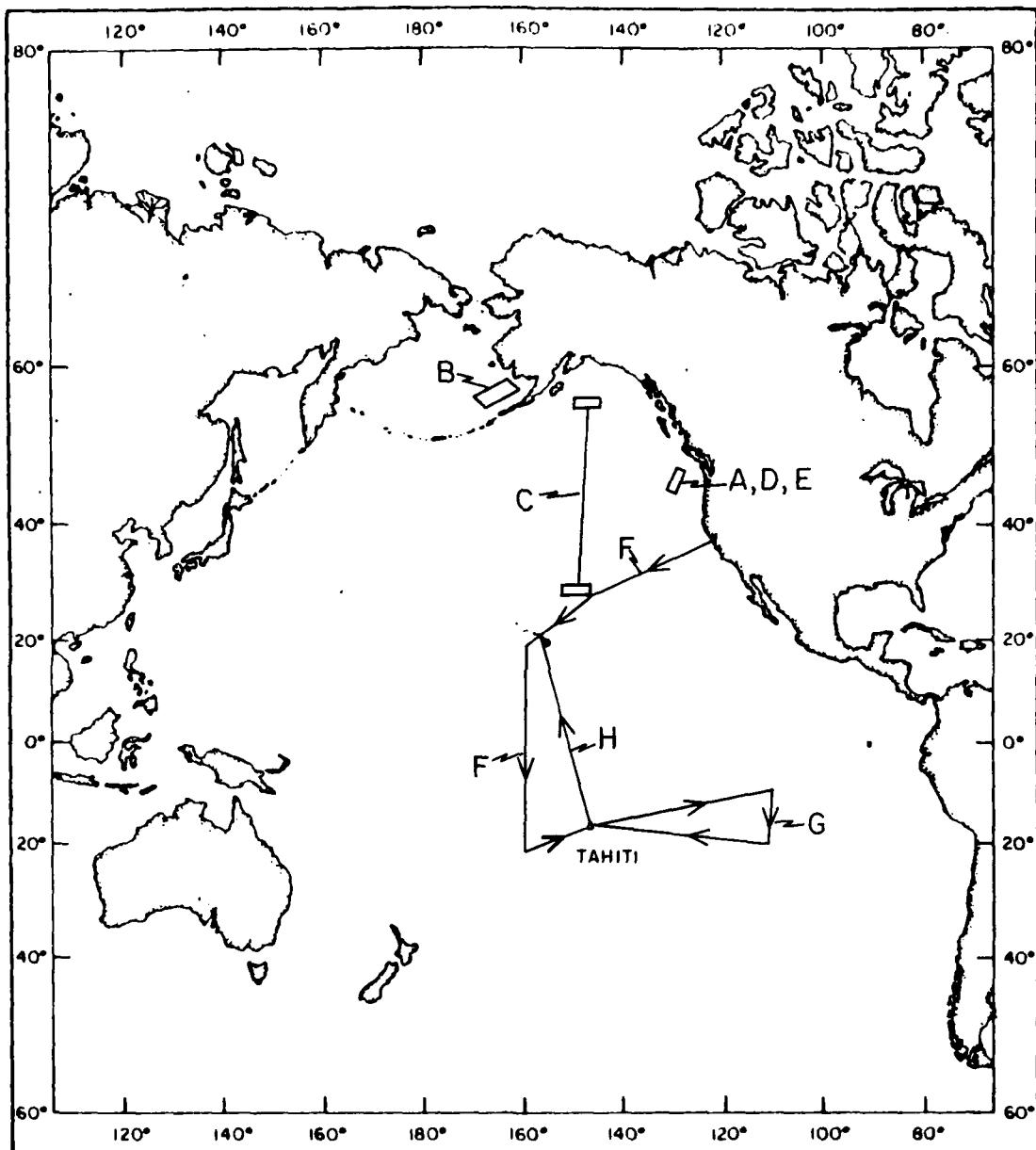
R/V THOMPSON  
1979 CRUISE TRACKS



- A. Dr. B.T.R. LEWIS, JAN. 2 / MAR. 11
- B. Dr. L. COACHMAN, MAR. 27 / JUNE 23
- C. Dr. S. EMERSON, JULY 5 / JULY 12 and AUG 25 / SEP. 1
- D. Drs. M. PERRY / G. ANDERSON / C. LORENZEN, JULY 16 / AUG. 2
- E. Dr. R. STERNBERG / C. NITTRUER, AUG. 3 / AUG. 16
- F. Dr. B. HICKEY, AUG. 16 / AUG. 20
- G. Drs. C. LORENZEN / B. FROST / M. PERRY, SEP. 3 / SEP. 29
- H. Dr. J. MURRAY, SEP. 29 / NOV. 1
- I. Dr. C. LORENZEN, NOV. 3 / NOV. 30
- J. Dr. E. LEOPOLD, NOV. 29 / NOV. 30

R/V THOMPSON  
1980 CRUISE TRACKS

v



- A. Dr. B.T.R. LEWIS, FEB. 27 / MAR. 2
- B. Dr. J. GOERING, MAR. 10 / JUNE 13
- C. Drs. C. LORENZEN / M.J. PERRY, JUNE 14 / JULY 14
- D. Dr. B.T.R. LEWIS, JULY 22 / JULY 27
- E. Drs. P. JOHNSON / J. DELANEY, JULY 30 / AUG. 29
- F. Dr. K. BRULAND, SEP. 11 / OCT. 27
- G. Dr. J. MURRAY, OCT. 31 / NOV. 29
- H. Dr. C. LORENZEN, DEC. 1 / DEC. 16

## BIOLOGICAL OCEANOGRAPHY

### *Mechanisms of Transfer of Energy and Biomass in Coastal Marine Ecosystems of the Pacific Northwest*

The objectives of this biological research program include a better understanding of the processes governing the communities of organisms in the water column, on the seabed, and in the surf zone. The field program is complemented by laboratory studies which emphasize a more detailed understanding of key processes and interactions.  
(Anderson)

Phytoplankton studies: Adaptation to low light intensity allows phytoplankton to improve their photosynthetic performance, hence their productivity and growth rates; such adaptions are important components of species' exploitative strategies for utilization of limiting resources. One mechanism of adaption to low light is an increase in the photosynthetic unit (PSU) size or the proportion of light-harvesting pigments to reaction center chlorophyll. PSU size, measured as the ratio of chlorophyll to P700, exhibits some variation among species grown under high light intensity. At low light intensities PSU size increases in most diatom species and in some flagellates.

At light intensities below those required to saturate photosynthesis (PS), the efficiency of PS per PSU is a function of PSU size. Species which adapt to low light by increasing PSU size show enhanced PS efficiency per PSU. In contrast, PS efficiency per chlorophyll  $\alpha$  varies inversely with PSU size. In several species grown at high light the PSU size was large; this may be significant for short-term adaption to fluctuating light fields in the mixed layer. The patterns of changes in PSU size and PS effi-

ciency have important implications for understanding and modeling primary productivity as a function of light in the ocean. (Perry, M.C. Larson)

In many pelagic ecosystems, nitrogen is a potentially limiting resource to phytoplankton production. A very large percentage of the cell's nitrogen is directly associated with the photosynthetic apparatus (as nitrogen in chlorophyll-binding-protein and carboxylating enzymes); these components may serve as reservoirs of protein-nitrogen and act as buffers against temporary depletion of nitrogen in the environment.

The ability of a species to utilize limiting concentrations of nitrogen, which is reflected in the structure (PSU size) and function (PS efficiency) of the photosynthetic apparatus, constitutes part of a species exploitative strategy. Research on changes in PSU size, ribulose bi-phosphate carboxylase activity, PS efficiency, and quantum yield of several species in response to nitrogen stress is also providing a molecular explanation for the physiological and photosynthetic changes that occur in phytoplankton subjected to nitrogen stress.  
(Perry, M.C. Larsen, Welschmeyer)

The role of autotrophic nitrifying bacteria in the oceanic nitrogen cycle is being investigated in relationship to the primary nitrite maximum in coastal waters of the northeast Pacific Ocean. Two specific immunofluorescent assays, developed in this laboratory, were used to enumerate two species of the two known genera of marine ammonium-oxidizing bacteria in samples from off the coast of southern California. These population estimates, in conjunction with  $^{15}\text{N}$ -

mates, in conjunction with  $^{15}\text{N}$ -nitrogen tracer measurements of oxidation of ammonium to nitrite, indicate that ammonium-oxidizing bacteria are most active in nitrite production at the depth of the nitrite maximum. Their activity is near zero in the upper euphotic waters above the primary nitrite maximum zone, implying light inhibition of nitrification. These differences in activity level of the *in situ* population are particularly interesting in view of the finding of nearly uniform cell numbers of the two species of bacteria with depth.

Variation in growth of the nitrifying population with depth is presently being investigated in Washington coastal waters using  $^{14}\text{CO}_2$  autoradiography. In combination with immunofluorescent enumeration of the population, autoradiography will allow direct determination of the proportion of cells actively assimilating carbon. A partial uncoupling of ammonium oxidation and  $\text{CO}_2$  assimilation by the nitrifiers could be implied by the lack of population structure observed previously. (Perry [Ward]; R.J. Olsen, Scripps Institution of Oceanography)

Plankton biomass or carbon is often chemically estimated by determining the ATP in the suspended matter (obtained by straining the sample through a 0.2 mm mesh), then multiplying the ATP concentration by a conversion factor from ATP to carbon of 250 (from phytoplankton studies). By means of a literature review, it was shown that in oceanic and coastal water samples, half or more of the measured ATP may be of animal origin. Because metazoans have carbon/ATP ratios materially lower (about a third, or perhaps even less) than the value of 250; the use of ATP measurements may lead to a considerable overestimate of plankton biomass. (Banse)

Zooplankton studies: Field observations, theoretical studies (Jamart et al., 1977), the results of factor analysis, and investigations on chlorophyll degradation products indicate that grazing and nutrient regeneration by zooplankton play significant roles in structuring the distribution and abundance of phytoplankton, particularly during the summer months. Our approach toward obtaining a quantitative understanding of phytoplankton-zooplankton interactions in this region is a combined field and laboratory program; simulation models and a conceptual model of the effect of species size on annual turnover rates continue to provide a theoretical context for the experimental investigations. The objectives of the field program are to quantify natural grazing rates zooplankton, including microzooplankton, and to determine the abundance and composition of the zooplankton assemblages. Laboratory studies focus on feeding and growth rates of copepods and on developing new experimental methods for assessing natural grazing pressure in the field.

Recent experimental field studies have emphasized measurement of the grazing impact of microzooplankton, which are often extremely abundant. Because microzooplankton, i.e., ciliates and copepod nauplii, cannot be individually manipulated at sea or separated from the overlapping size range of phytoplankton, they typically are contaminants in routine phytoplankton growth experiments. Consequently, these experiments measure the resulting difference between phytoplankton growth and microzooplankton grazing rather than the actual phytoplankton growth rate which is desired. An experimental technique that allows the investigator to separate the components of phytoplankton growth and grazing has been developed. While the effect of microzooplankton graz-

ing often does not constitute a major correction to estimates of phytoplankton growth, there are circumstances in which the grazing that occurs during the phytoplankton growth experiment leads to an underestimation of phytoplankton growth by as much as a factor of two. (Landry, Zakar [Hassett])

Feeding and growth rates of the last four naupliar stages of *Calanus pacificus* at 12°C as a function of food concentration have been determined. Near-optimum growth was observed at food concentrations as low as 43-49 mg carbon liter<sup>-1</sup>. Under optimum food conditions, the gross growth efficiency was about 33% and the assimilation efficiency, assuming a respiration rate extrapolated from observations on young copepodids, was about 62%. These data are incorporated into a preliminary carbon budget that represents feeding, defecation, respiration, and growth rates of the naupliar stages of *C. pacificus*. The principal objective of current research is to measure respiration rates of the naupliar stages, since there are indications in the literature that naupliar stages function metabolically quite differently from young copepodid stages. (Frost [Smayda]).

Laboratory experiments on the ingestion rates of marine copepods have generally demonstrated a critical food concentration beyond which ingestion rates may increase linearly with food concentration throughout the range of food experienced in nature. Presently, sensitive assays are being developed for measuring digestive enzyme activities of copepods. These assays will provide a means of testing, under controlled conditions, the hypothesis that marine copepods are able to acclimate activity levels of digestive enzymes in response to changes in ambient food concentrations. (Landry [Hassett])

Chlorophyll degradation products: Chlorophyll degradation products, primarily phaeophorbide  $\alpha$ , are produced in the marine environment by the passage of the chlorophyll  $a$  molecule through the gut of a herbivore. These products are found in finely dispersed particulate matter, in zooplankton fecal pellets, and incorporated within the sediments. We have developed a High Pressure Liquid Chromatography system to quantitatively measure these pigments.

Since these pigments originate in the phytoplankton, samples collected by sediment traps provide information on the duration and intensities of algal blooms. For example, the commonly excepted sequence one expects to find in temperate regions has not been noticed in Dabob Bay. The only consistent feature is that algal blooms are not seen between June and September. Blooms have been detected by the traps in October (1977 and 1980), December (1979), February (1980), March (1977), and May (1980). The intensity of the bloom seems to vary from year to year by a factor of about 15X on the basis of pigment flux. Maximum carbon flux associated with each of the blooms occurs within one-two months after the maximum pigment flux. This is reasonable to expect since fecal pellets resulting from herbivorous grazing contain only a small fraction (5-10%) of the ingested algal carbon. The remainder is incorporated into other compartments of the food chain.

Numerous sediment trap samples collected off the Washington coast fall within the range of phaeophorbide flux found in Dabob Bay; suggesting that results and deductions from the long-term studies in Dabob Bay are applicable to the open Washington coast. (Lorenzen)

Sensitivity analysis of a model of phytoplankton growth: Recently, a numerical two-dimensional (time and depth) model describing phytoplankton growth and nutrient distribution off the Pacific Northwest coast was developed. The model consists of coupled integro-partial differential equations expressing conservation of chlorophyll *a*, nitrate, and ammonium. The relevant physical and biological processes are represented by conventional functions and parameters wherever possible. The system is "closed" by specification of grazing pressure and light intensity. A long-term simulation over spring and summer months represents well the main features of observed chemical data and biological variables, including the formation and deepening of a subsurface chlorophyll maximum.

During the past year, we completed a sensitivity analysis of the system by comparing the "standard run" described above with the results of twenty numerical experiments, in each of which a single function or parameter in the model is modified. The nature of the results of the experimentation is explained by the following hypothesis: for the model equations originally used in the simulation, the phytoplankton-nitrogen system, as it responds to zooplankton and light intensity, evolves in such a way that the amount of carbon ingested by herbivores is determined mainly by the resources available to primary producers. Physical constraints affect the utilization of these resources. It appears that in a dynamical sense the chlorophyll distribution adjusted in time and depth so as to optimize the transfer of carbon to secondary producers. (Winter, Banse [Jamart])

Benthos studies: Investigations of biomass and energy transfer in the benthos use two approaches --

component process studies and long-term monitoring. Field experiments and theories derived from them have been used iteratively to investigate component processes of dispersal, recruitment, and deposit feeding. The net effects of these and other community processes are being monitored empirically via a long-term (15-year) sampling program in the main basin of Puget Sound. In addition, taxonomic efforts that are necessary to provide unambiguous identification of the important species (e.g., the target of deposit-feeding experiments) are being carried out.

Investigations into the foraging strategies of deposit feeders continue. Experiments with members of several major taxa have demonstrated the size selective ingestion predicted by our earlier model. Also, as suggested by this model, laboratory observations of animals' feeding behavior have indicated that some deposit feeders are capable of varying their ingestion rate in response to varying food quality. A more detailed model developed to investigate the relationship between optimal ingestion rate and food quality indicates, under a broad range of assumptions, that these two parameters should be directly related. Preliminary experimental results confirm this prediction. Current efforts are aimed at developing accurate methods for controlling and assessing food quality to allow further investigation of the food quality-ingestion rate relationship. (Jumars [Taghon])

The revision of the benthic polychaetes of Washington and British Columbia, the best-studied parts of the Oregon Biogeographic Province, has been completed. The second and last volume treats 292 species or subspecies of sedentariate and archiannelid polychaetes. Including the errantiates, approximately 485 benthic polychaetes are now known from

Washington and Oregon, landward of the 200-m isobath of the shelf. Of these, 44% occur also in the northern part of the San Diego Biogeographic Province (i.e., on the shelf off southern California) and 45% also on the cool-temperate northwest Pacific continental shelves.

Among the Cossuridae and Maldanidae, the last families studied for the handbook, five new records were added to the region, and additions to the descriptions of some species were made. The maldanid *Axiothella torquata*, one of the new records, is found in large abundance in the intertidal of Boundary Bay; it may have been introduced when oysters from the North American East Coast were transplanted there. (Banse)

Surf-zone studies: The surf and beach systems along the Washington and Oregon coasts are unsurpassed for a study of the surf ecosystem as they maintain unusually high standing stocks of plant and animal biomass. Surf diatoms constitute the major marine plant biomass; they are, therefore, the main food source of many animals, including razor clams, a major industry in parts of the area. Our experimental studies have been directed toward an understanding of energy flow and transformation of materials in this unique ecosystem. (Lewin)

A 14-month study of surf diatoms was designed to (1) establish their range in Washington and Oregon, (2) relate species abundance to the type of beach and coast, (3) relate changes in species abundance to changes in environmental variables, such as nutrient concentrations, salinity, air and water temperatures, rainfall, river discharge, and upwelling.

The species comprising the surf blooms are *Chaetoceros armatum* T.

West, a filamentous centric diatom, and *Asterionella socialis* Lewin & Norris, a colonial pennate diatom. They range from Port Grenville, Washington, to Cape Blanco, Oregon. Data for the statistical treatments were collected from 12 beaches in Oregon and one, Copalis Beach, in Washington, the site of a long-term sampling program. On the basis of cell densities, the beaches were arranged in four groups: high ( $> 10,000$  cells/ml), medium (10,000-1,000 cells/ml), low ( $< 1,000$  cells/ml), and no surf diatoms present. Surf diatoms were found at all beaches except the two southernmost Oregon localities.

Discriminant analysis showed that the four groups of beaches could also be completely separated by three discriminant functions composed of four physical variables: offshore bottom slope, percent chlorite, percent montmorillonite, and beach length. Topography (i.e., a gentle bottom slope resulting in shallow water and a well-developed surf zone) appeared to be the variable of prime importance in determining whether or not a particular beach-surf system can sustain persistent diatom blooms in the surf. The absence of surf diatoms at two beaches can probably be explained by their steeper slope of beach faces, steeper offshore bottom slope, narrower surf zone, and different clay mineral composition.

A statistical technique (stepwise multiple linear regression analysis) was employed to relate changes in diatom abundance over time to changes in environmental variables. Regression analysis was applied to the data from October through April, since the cell counts of *A. socialis* could be normalized only over this time period. The variables measured were better able to explain the variance of the cell counts of the dominant species (*C.*

*armatum*) than that of *A. socialis*. Low air temperature, low water temperature, and low salinity were associated with increased number of both species of surf diatoms. As nutrients were constantly being utilized by the phytoplankton cells, the nutrient concentrations were inversely proportional to the phytoplankton density and yielded high negative correlations. The place of origin of the sample explained a large part of the variance in cell counts, implying that the physical characteristics of the coastline (beach length, beach slope, offshore bottom slope, etc.) may be more critical than the other environmental conditions. (Lewin [Garver])

The large data set acquired from long-term sampling at a single beach, together with that from the multi-beach sampling program, have provided considerable insight into the response of surf-zone diatoms to specific environmental variations and also contributed to a general qualitative understanding of the surf-zone ecosystem. We propose, therefore, to explore the feasibility of constructing quantitative models of at least a portion of the surf-zone ecosystem. (Lewin, Winter)

#### *Relationship between Nitrate Uptake and Growth in Marine Phytoplankton*

Primary productivity and species composition are often controlled by the supply of nitrogen to the euphotic zone of the ocean, but the utilization of nitrate is poorly understood and recently has been found to be particularly complex. (See also p. 1.) Experiments have been designed to aid in our understanding of the relationship between nitrate uptake and growth in marine phytoplankton. We are examining, both in the laboratory and in the field, the ability of several species of marine phytoplankton to

store nitrate and the products of nitrate assimilation. Our studies include elucidating the enzymatic pathway for nitrate assimilation and determining the metabolic regulation of nitrate uptake and assimilation. (Ahmed, Dortch [Clayton])

#### *Nanoplankton Studies*

Measurements of the carbon uptake by different size fractions of plankton have shown that nanoplankton is the most important group of primary producers in the subarctic Pacific. The purpose of this project is to identify the nanoplankton species most important in primary production and to generalize as to the important algal classes.

Water samples collected in the Gulf of Alaska were each treated on shipboard in two ways: prepared for examination with the scanning electron microscope (SEM) and preserved in buffered formalin. The SEM samples were used to quantitatively determine species abundance. The species composition differed considerably in the SEM preparations from that in the subsamples preserved in formalin. For example, the following species were not found in the latter subsamples but were the most abundant forms in the SEM preparations: two species of *Cryptomonas* (Cryptophyceae), *Phaeocystis puchettii* (Prymnesiophyceae), *Minidiscus trioculatus* and *Nitzschia cylindrus* (Bacillariophyceae), and a group of siliceous forms tentatively identified as choanoflagellate cysts. In the SEM samples we also observed many flagellated organisms which, however, we have been unable to identify. To aid in the identification of these organisms and the abundant cysts referred to above, we are now expanding our study to use the transmission electron microscope. A more accurate representation of the nanoplankton community than has been possible formerly should result. (Booth, Lewin)

### *Respiration and Intrinsic Growth Rates of Ciliated Protozoans and Very Small Metazoans*

In a review of the Production/Biomass quotient, Banse and Mosher (1980) suggest that very small size may provide a refuge from predation. This would lead to lowered mortality and thus require lowered production, with the concomitant lowering of daily ration and respiratory expense. Tentatively, the lowered mortality was regarded as the evolutionary reason for the lowered respiration rate of very small metazoans (relative to that calculable from the allometric relation for large invertebrates).

The respiration-to-body mass relation ( $R = a M^b$ ) of very small metazoans is being reviewed. Data from the literature for rotifers, mites, and oligochaetes confirm the relation known so far only for free-living nematodes, i.e., the exponents of the allometric respiration relations do not differ significantly from the usual 3/4 power, but the proportionality coefficients  $a$  are between those of larger metazoans and protozoans.

The relation between intrinsic growth rate ( $r$ ) and body mass ( $r = cM^d$ ) of small metazoans and ciliated protozoans is also being reviewed. Rotifers seem to be scaled-down versions of large metazoans, i.e., the proportionality coefficients are about the same -- not what one would expect from the predation refuge hypothesis. Nauplii and copepodites of two pelagic copepods (*Acartia* spp.) with isochronal development, however, have very low coefficients of exponential growth. Likewise, species of benthic meiotauna of three phyla possess small  $r$ -values which are in part even lower than those of ciliates of the same size.

Power functions like these have been applied to abundance measurements in the plankton and benthos to estimate rates of respiration, for example, even though it was known that the precision of such estimates is not great. This review further substantiates this by showing the great uncertainty for the body mass of small zooplankton and benthic meiotauna and argues for material investments in direct measurements of e.g., feeding rates. (Banse)

### *Production Control Mechanisms of the Subarctic Pacific Ocean*

The open-water ecosystem of the subarctic Pacific is unique among temperate-boreal oceans in that there is no substantial seasonal variation in phytoplankton standing stock. We hypothesize that grazing by zooplankton controls phytoplankton growth. Two simulation models that have been developed satisfactorily represent this phenomenon but suggest extreme sensitivity of the phytoplankton-zooplankton interaction. To refine the hypothesis, precise details of the life history patterns of the dominant planktonic suspension feeders, the copepods *Neocalanus cristatus* and *N. plumchrus*, are needed.

We are now collecting a two-year series of vertically stratified zooplankton samples from the Canadian Coast Guard weather ships at Ocean Station P (50°N, 145°W) in the eastern subarctic Pacific. The first sampling results indicate that the life cycles are certainly different than previously thought. In particular, *N. plumchrus* overwinters in all of its copepodite stages rather than just in the fifth. We believe this implies that a wide range of sizes of this form may be present near the surface early in spring which would provide strong

grazing pressure for control of plant stocks as plant growth rates increase. (Frost, C.B. Miller, Oregon State University)

#### *Subarctic Pacific Ecosystem Research: A Planning Project*

Trophic interactions in marine pelagic ecosystems are the subject of the most successful theories in ecology. These theories are embodied in process models that predict the time course of plant and animal abundances. The oceanic subarctic Pacific provides a special situation that will give oceanographers field comparisons of very great power for advancing the theory generally and the process models in particular. In this region there is an apparently permanent balance between phytoplankton growth and grazing. Repeating this balance in process models provides a test of model adequacy. Field and experimental measures of model variables and parameters will allow critical tests of our understanding of the responses of phytoplankton, grazers, and predators to each other and to the physical problems of the pelagic habitat.

We are developing a proposal to carry out a major, coordinated study of pelagic ecosystem processes in the oceanic subarctic Pacific. This program is called SUBarctic Pacific Ecosystem Research, project SUPER. Approximately 30 scientists will participate in a SUPER workshop at the Lake Wilderness Conference Center in February 1981. The anticipated outcome of the workshop is a plan for field studies of all of the processes relevant to pelagic ecosystem dynamics in the subarctic Pacific. (Frost; C.B. Miller, Oregon State University)

#### *Relative Abundance of Copepod Species in Temperate-Boreal Pelagic Communities*

This project has the broad goal of identifying and analyzing the processes that affect the relative abundance of copepod species in marine epipelagic communities. The research currently stresses study of certain suspension-feeding calanoid copepods of the genera *Calanus* and *Pseudocalanus* which are major components of the zooplankton in temperate-boreal oceans of the Northern Hemisphere. Laboratory studies on feeding behavior, growth rates, and reproductive rates permit quantitative description of intrinsic growth rates of copepod populations and the effects on population growth of several important environmental variables. To understand the role of predation in altering relative abundance of copepod species, laboratory experiments on feeding behavior of important planktonic carnivores are being carried out. Results are being integrated into simulation models of plankton to investigate theoretically the processes that control and modify interspecific interactions among suspension-feeding copepods. Data are being obtained on the dynamics of natural populations of copepods occurring in Puget Sound.

Experiments on the selective feeding in adult females of *Calanus pacificus* have been completed, and the results are available in recent publications. Similar investigations are now being made with *Pseudocalanus* sp. Analyses of rates of growth and development of copepods under controlled laboratory conditions indicate that there are strong interactions between temperature, food abundance, and body size. That is, comprehensive understanding of patterns of growth can be achieved only with multifactor experiments. Laboratory studies of reproductive

rates of *Calanus pacificus* at different food concentrations and temperatures generally agree with the results of laboratory studies of growth rate. Reproductive rates have been estimated for populations in Dabob Bay; results indicate that for much of the year the population is severely food-limited. Experimental procedures have been developed to examine feeding rates and possible selective feeding in the predatory planktonic copepod *Euchaeta elongata*. The older copepodid stages of *E. elongata* can feed on copepod prey ranging in size from the nauplius I to the adult female of *Calanus pacificus*. However, they prey most efficiently on intermediate-sized (about 1mm length) suspension-feeding copepods. We are now considering the mechanisms for this feeding behavior in the context of optimal foraging and encounter-capture efficiency. A field study of diel vertical migration in *Pseudocalanus* and the potential causal mechanisms is currently underway. (Frost, Runge [Yen, Ohman])

#### *Selective Predation by Cyclopoid Copepods*

The general goal of this project is to evaluate the implications of selective predation by invertebrate predators on the size and species composition of pelagic marine ecosystems. An integrated approach of experimentation and quantitative observation is being used to determine predation rates and prey selection by the cyclopoid copepods *Corycaeus* and *Oithona*, numerically dominant predators in Puget Sound, with emphasis on understanding selection patterns in terms of the basic processes of predator-prey interactions, i.e., encounter, perception, attack, and escape. We determine encounter frequencies (functions of predator and prey swimming velocities and the range at which the predator can detect prey) and the pro-

babilities of predator attack and prey escape from recorded observations of predator-prey interactions made with a video-microscope system. These data serve to generate a predictive model of prey selection which can be tested experimentally when predators are given mixtures of different prey. Field collections to assess the densities and distributions of cyclopoid copepods and their prey will allow us to estimate the impact of these predators on natural populations of zooplankton. (Landry, Zakar)

#### *Distribution and Abundance of Zooplankton in the Columbia River Estuary*

As part of the multidisciplinary Columbia River Estuary Data Development Program, the distribution and abundance of zooplankton, including fish larvae, are being investigated. (See also p. 21.) The one-year field program was designed to carry out net and acoustic sampling at selected stations every two weeks. However, extra sampling has been undertaken to attempt to identify effects of recent volcanic eruptions. (English, Heron, Kisker, Roetcisoender, Stahl)

#### *Population Dynamics and Feeding of Larvaceans*

Larvaceans are common marine plankters which build mucous houses to collect the very small particles that constitute their food. Little is known of their quantitative biology. Our approach to these studies is twofold: experiments using very large floating plastic columns anchored in Saanich Inlet, B.C. of the Controlled Ecosystems Population Experiments (CEPEX) and laboratory experiments. "Natural" enclosed populations of the cosmopolitan larvacean, *Oikopleura dioica* Fol, were studied in the 1300 m<sup>3</sup> water columns of CEPEX during two long-term exper-

iments (90 - 120 days). The larvaceans responded quickly ( $r = 0.7 \text{ day}^{-1}$ ) to nano- and bacterioplankton blooms, which resulted in rapid maturation of already present juveniles and in increased survival of young larvaceans. The subsequent cohorts, strikingly similar in number and duration to published descriptions of eruptions of *O. dioica*, showed growth rates (individuals doubled their weight each day) and generation times (7-10 days at 13°C) comparable to laboratory populations.

*Oikopleura dioica* removes bacterioplankton  $<1 \mu\text{m}$  diameter at least as efficiently as they filter nanophytoplankton  $> 5 \mu\text{m}$ , regardless of larvacean body size. Even though individual feeding rates may be high ( $> 100 \text{ ml/day}$  for mature animals), grazing rates are so dependent on larvacean size that, in conjunction with the size-frequency distribution of the population, the population generates little grazing effect. Thus, although the dynamics of the larvacean populations are very dependent on the dynamics of the small size fractions (nano- and bacterioplankton), *O. dioica* has little effect on its food populations, consuming less than 5% of its prey biomass on the average and less than 20% at maximum. (Banse [K. King])

#### *Effects of UV-B Radiation on Near-Surface Zooplankton*

Studies are continuing on the ecological effects of enhanced mid-range ultraviolet radiation -- the level that would result from pollution of the stratospheric ozone layer. Though the oceans are relatively opaque to UV radiation, increases in incident UV may affect organisms living within the first few meters of the sea surface or seasonally occurring there.

Shrimp and crab larvae and euphausids, collected in Puget Sound, tolerated UV-B irradiance up to threshold levels with no significant reduction in survival or developmental rates compared to control organisms. Beyond threshold levels, activity, development, and survival rapidly declined. The apparent UV thresholds are near present incident UV levels but are exceeded late in the season of surface occurrence of each species. UV increases resulting from ozone depletion may significantly shorten this season.

Recent experiments suggest that a number of common near-surface zooplankton species do not have a timely response to increased UV and therefore would not alter their near-surface occurrence. (Damkaer, Heron; D.B. Dey, Northwest and Alaska Fisheries Center)

#### *Biomagnetic Studies*

Experiments with sockeye salmon fry show that they are able to sense the horizontal component of the earth's magnetic field. Unlike some animals such as homing pigeons, honey bees, and certain mud bacteria, sockeye fry do not contain single domain magnetite particles. Although several potential sensing mechanisms have been eliminated, we have not determined, as yet, how the fry detect the geomagnetic field. (Merrill; E.L. Brannon, T. Quinn, College of Fisheries)

#### *Flux of Organic Particulates to the Sea Floor*

Sediment traps provide a class of data relevant to food chain dynamics that previously was unavailable. Analyses of sediment trap samples make it possible to document the flux of organic particulates through the water column and their final deposition on the sea floor.

The traps are calibrated *in situ* with the use of lead-210 and have been shown to collect 119 ±19% of the material which arrives on the sea floor. (See also pages 3, 16.)

Two annual cycles have been completed in Dabob Bay, Washington, and we are well into the third. Eventually we expect to complete five years of observations, with the aim of documenting temporal variations in the onset and intensity of phytoplankton blooms, the importance of the control of phytoplankton blooms by herbivorous zooplankton, and the significance of the control of nutrient cycles by both herbivores and physical processes. (Lorenzen [Copping, Hall, Welschmeyer])

#### *Benthic Organism-Sediment-Flow Interactions*

Studies of marine benthic biology, sediment transport, and stratigraphy have remained generally separate, even though processes important to all three disciplines are closely coupled in nature. Our recent work has been aimed at determining some important organism-sediment-flow interactions. Specifically we have been studying: (1) potential effects of surface deposit feeders (especially via particle selection) on stratigraphic patterns, (2) effects of tube-building infauna on sediment stability, and (3) effects of near-bottom flow and sediment transport on organism behavior.

A simple, discrete-time Markov model has been generated to predict effects of particle selection by surface deposit feeders on particle residence time in surficial sediments. Initially discounting flow effects, the model predicts that more strongly selected particles would remain near the sediment surface for a greater period of time.

If the probability of lateral advection is allowed to differ between fecal pellets and "free" sediments, then measured particle selection by deposit feeders may either increase or decrease particle residence time in surficial sediments. Our laboratory experiments indicate that the direction of this difference in transportability depends strongly on the size composition of the bed. (Jumars, Nowell)

It is commonly believed that the presence of "dense" assemblages of animal tubes create locally a more stable bed. Our recent controlled laboratory experiments demonstrate that clusters of protruding tubes created by an Oweniid polychaete have a destabilizing influence on the bed at densities previously reported from field studies as "stabilizing." We suggest that other, unaccounted-for factors, such as microbial binding of sediment, may be responsible for this apparent contradiction. (Nowell, Jumars [Eckman])

To investigate the effects of near-bottom flow and organism behavior, experiments were designed with respect to organism behavior under natural conditions of flow and to determine the effect of flow on feeding behavior. Spionid polychaete are generally considered to be surface deposit feeders. However, three species that commonly use their two feeding tentacles to pick up sediments from the bed were observed, at moderate flows, to form their tentacles into helices and hold them up into the flow, thereby capturing material in suspension. This switching of feeding behavior, which was caused by increased fluxes of suspended matter (not just by the flows themselves), may be a general feature of dynamic benthic environments. (Jumars, Nowell [Taghon])

### *Role of Predation in Soft-bottom Benthic Successions*

Predation is a fundamental factor of soft-bottom benthic community structure. Nevertheless, the most abundant, and potentially the most important, group of soft-bottom benthic predators, the microphagous surface deposit feeders, has rarely been studied to assess the effect of this form of predation on community structure. Mainly this neglect is due to methodological difficulties. Microphagous surface deposit feeders, primarily small polychaetes and crustaceans, are difficult to manipulate in the field, while their prey, the settled larvae and juveniles of macrofaunal and meiofaunal taxa, are difficult to enumerate in field samples and often impossible to identify in the guts of their predators.

Improved techniques are being used to evaluate the role of predation in structuring soft-bottom communities. Highly selective manipulations of surface deposit feeders in succession experiments in the field directly test whether they inhibit the recruitment of other taxa. To clarify the mode of inhibition, the gut contents of the manipulated surface deposit feeders are analyzed, using a refined immunological gut content assay.

This immunological assay is specific for individual prey proteins in the gut of the predator. The proteins are detected by subjecting the predator's gut contents to electrophoresis and reacting the proteins with monospecific antisera. With this highly sensitive assay it is possible to detect minute quantities of prey protein in the guts of microphagous predators. (Jumars [Gallagher, Taghon])

### *Community Development on Submerged Artificial Surfaces*

Basic questions of succession as framed by Connell and Slatyer (1977) are being examined. In particular we are testing the importance of certain initial colonizing species to the community developing on submerged artificial surfaces. Extensive series of identical substrates are submerged 30 feet below the surface at a site in northern Puget Sound. The substrates are regularly examined until they have been colonized by an encrusting bryozoan. On some substrates the bryozoan is oiled, on others the same bryozoan species is removed manually. The remaining unaltered substrates serve as controls. Our observations of subsequent histories, with and without the bryozoan being present, will indicate the effect of this species on the developing community. Encrusting bryozoan species, such as the one used in these experiments, have been shown from previous experiments to be more sensitive to oil than are either hydroids or barnacles. It seems possible that a small-scale oil spill might cause species deletions comparable to those in our experiments and thus effect species differentially. (Schoener [Copping, Ota])

The possibility of the occurrence of general patterns in community development on newly submerged hard substrates has elicited this research project. Data suggesting that such patterns exist were obtained from Navy experiments conducted at various Northern Hemisphere latitudes. These patterns deal primarily with the rate of species accumulation on identical substrates.

In Puget Sound our primary goal is to determine whether such development patterns hold for different types of sessile benthic communi-

ties. Submerged substrates at two localities were observed over a two-year period. There were two predominant types of sessile species, a bryozoan community at one locality and a tunicate community at the other. Interestingly, similar patterns in community development were seen even though the communities themselves differ taxonomically. Based on these results, general models of community structure will be constructed. The generality of development under unpolluted conditions suggests that this measure may serve as an indicator of pollution stress; this concept will be examined further.

In addition to assessing the species abundance on panels, the types of colonists and their change with time were noted. Our results, however, are opposite to those of Jackson (1977) for tropical communities, in that solitary species become predominant as time progresses. Comparisons of community development on our two-year old substrates with that of 15-20 year old floats confirm our results over an even longer time scale. (Schoener [Greene])

## CHEMICAL, BIO-, AND GEOCHEMICAL OCEANOGRAPHY

*Comparative Studies of Enzymes Involved in Ammonia-N Assimilation in Marine Phytoplankton*

In constructing dynamic models of marine phytoplankton communities, it is essential to measure the rates of key metabolic processes that determine growth, multiplication, and succession. Although the role of nutrients in limiting primary production in the sea is now well recognized, measurements do not readily yield "real time" data; therefore there is a need to develop new methods, such as sensitive enzymatic assays, to assess the nutritional status of marine phytoplankton. The enzymes involved in the direct assimilation of ammonia-N to an intermediary metabolite resulting in the formation of amino acids are of vital importance. However, only glutamate dehydrogenase (GDH) has been studied in some detail. The enzymes glutamine synthetase (GS)/glutamate synthase (GOGAT), which can be many times more efficient in ammonia assimilation, only a few years ago were thought to be nonexistent in eukaryotes. We, however, have already demonstrated the existence of the GS/GOGAT pathway in several marine phytoplankton species, and studies are currently underway to study the kinetic and regulatory properties of these enzymes in marine phytoplankton. We are also in the process of determining the relationship between external N-nutrient concentration and internal nutrient, amino acid, and GS/GOGAT and GDH levels, using batch as well as chemostat cultures. The effect of light/dark cycle on various metabolic parameters will also be examined. The knowledge gained in the laboratory is expected to be usefully tested and applied in field experiments with natural phytoplank-

ton populations in Puget Sound, Washington. These studies are expected to enhance our understanding of the process of nitrogen assimilation and nutrient limited growth in the marine environment. (Ahmed, Dortch [Bressler, Clayton])

*Chemical Parameters and Microbial Populations in Organic Matter Diagenesis in Anoxic Marine Environments.*

While the phenomenon of early organic matter diagenesis is well recognized, the associated rates, processes, and pathways are poorly understood. Most work in the past relied on studying the production of sulfide which is presumably coupled to the organic matter decomposition. However, both the dissimilatory reduction of sulfate (a respiratory substrate) or the formation of sulfide (the respiratory end product) are at best indicators of the process of sulfate reduction and should not be relied upon as exclusive measurements of organic matter diagenesis in anoxic marine environments. Supplementing the measurements of sulfate reduction and sulfide production, direct measurements of electron transport system (ETS) activity, cytochrome C, and ferricyanide reducing activities, as well as determinations of ATP levels and energy charge, are being made to describe the changes occurring within the anoxic ecosystems of Lake Nitinat and Saanich Inlet, British Columbia. These studies are being complemented and correlated with the determination of the types of microbial (bacterial) populations that are primarily responsible for the diagenetic changes. Thus vertical profiles of bacterial diversity and population have been constructed and the bacterial isolates identified

after extensive biochemical and growth tests by a complete placement program (cluster analysis). It is expected that these studies will lead to a better understanding of the contribution of various bacterial populations (sulfate reducers as well as fermenters) to the diagenetic reactions and therefore to a better understanding of the overall diagenetic processes. (Ahmed [V. Johnson, S. King])

#### *Hydrocarbons in Puget Sound*

The goal of this continuing research is to assemble a unified picture of origins, pathways, and ultimate fates of hydrocarbons in the relatively uncontaminated environment of Puget Sound and the Washington coast. (See also p. 16.) The current phase of the program seeks to increase understanding of

- 1) the relative importance of polynuclear aromatic hydrocarbons (PAH) sources to the environment, including marine vs. terrestrial sources and the input of preformed PAH vs. in situ production of PAH;
- 2) the characterization and importance of aliphatic hydrocarbon sources, including input from rivers, METRO sewage effluents, planktonic organisms, and atmospheric dust-fall;
- 3) the distribution and characterization of nitrogen-containing hydrocarbon analogs in marine sediments and organisms.

Marine-derived hydrocarbons recognized in the sediments include pristane and a suite of multi-branched compounds containing 20, 25, and 30 carbon atoms. The latter suite appears to be related to

hydrolysis products of some microbial antibiotics. Sediment-core and sediment-trap studies demonstrate that pristane and marine-derived organic matter in general are preferentially remineralized near the sea-sediment interface resulting in the accumulation of material closely resembling terrestrially-derived organic matter.

Temporal distributions of total PAH and aliphatic hydrocarbons in  $^{210}\text{Pb}$ -dated sediment cores indicate that concentrations of both chemical classes have increased by up to a factor of 10-50 over the last 100 years. These increases are most pronounced near the cities of Seattle and Tacoma and implicate developing urban centers, rather than oil refineries to the north, as the primary source of anthropogenic hydrocarbons. The major components of this urban-derived mixture are PAH,  $13\alpha, 17\beta$ -diasteranes,  $17\alpha$ ,  $21\beta$ -triterpanes, and an unresolved complex mixture of branched and cyclic hydrocarbons. Although it was found that marine plankton did not produce any of the PAH, zooplankton fecal pellets account for ~100% of the PAH sediment flux.

In contrast to the increasing anthropogenic component in the most recent Puget Sound sediments, naturally-derived compounds are present at fairly constant levels in all samples. Perylene is one of the few PAH that appears to be naturally derived; however, the source is unknown. Aliphatic hydrocarbons from natural terrestrial sources include a suite of fossil isoprenoid and normal alkanes, additional normal alkanes from leaf waxes of vascular plants, and diterpenoid and some triterpenoid hydrocarbons. Concentrations of aromatic organosulfur compounds in the sediments are also constant over time, and the major source appears to be atmospheric input from natural

sources such as forest fires. (Carpenter, Hedges, Barrick [Prahl, Furlong])

*Chemical and Geochemical Studies off the Washington Coast*

Integrated field, laboratory, and theoretical programs to gain a better understanding of the processes that supply and transport various chemicals to the communities of organisms in the pelagic, benthic, and surf-zone environments are continuing. Our primary emphasis is in determining how energy related, potentially hazardous trace chemical species are injected, distributed, sorbed, stored, metabolized, and ultimately disposed of by coastal marine ecosystems of the Pacific Northwest. We have concentrated on several basic processes and the development of methodologies and expertise to study them. They include: (1) vertical transfer of trace chemicals from the surface to the underlying water and sediment; (2) transfer of certain chemicals from the sediment back into the overlying water column; (3) redox processes which besides changing valence states of certain chemicals may alter their precipitation/dissolution tendencies, their biological availability, and/or toxicity.

Sediment-trap studies: Several recent studies have indicated that fecal pellets are an important transfer agent for particulate matter and numerous species through the water column. Zooplankton fecal pellets are a readily identifiable component of suspended particulate matter and can be collected efficiently with sediment traps. (See also pages 3, 10.)

A one-year time series of consecutive monthly sediment-trap deployments was carried out at a well-defined location in Dabob Bay, Washington, to determine seasonal

variations in fluxes and to establish quantitatively the role of the vertical transport by the fecal pellets. This locality was chosen as the initial study area for the following reasons: (1) It is removed from direct inputs of major rivers; (2) Horizontal advection below the thermocline is minimal (Kollmeyer, 1965); (3) Sedimentation is primarily controlled by biological processes occurring in the overlying water column, in which the zooplankton are dominated by calanoid copepods which produce relatively robust fecal pellets; (4) valuable ancillary information describing the physical, chemical, and biological oceanography of the bay are available (Kollmeyer, 1965; Ebbesmeyer et al., 1975; Shuman, 1978). The first two reasons are particularly important because large inputs of riverborne particulates would obscure any quantitative assessment of the role of fecal pellets as agents of sedimentation, and horizontal advection could greatly alter the efficiency with which different particles are collected by sediment traps (Staresinic et al., 1978).

The large particle fluxes of mass and several elements and compounds obtained from sediment trap collections integrated over the 11-month period were compared with the annual total fluxes of mass and the same elements and compounds to the sediments (determined from analyses of surficial sediments and  $^{210}\text{Pb}$ -derived sedimentation rates). Results for the elements believed to be relatively unreactive after deposition in the sediments show that the traps collect essentially all of the flux of these species to the sea floor. Two elements, C and Mn, appear to have greater fluxes in the traps than accumulate in the sediment. The apparent excess of organic carbon in the traps turns out to be nicely balanced by oxygen con-

sumption rates of the benthos in Dabob Bay as measured by Christensen (1974). In several other coastal/estuarine regions such as Narragansett Bay, manganese diffuses back out of the sediments to the overlying seawater (Graham et al, 1976). We believe this behavior explains why higher fluxes of Mn are observed in the traps than actually accumulate in the sediments.

Zooplankton fecal pellets quantitatively account for 100% of the polynuclear aromatic hydrocarbon removal to the sediments at the station in Dabob Bay. Hydrocarbons derived from marine plankton undergo rapid and preferential remineralization compared with terrestrial-derived hydrocarbons.

At one locality (in Dabob Bay), zooplankton fecal pellets are the major agent vertically transporting both inorganic and organic chemicals from the surface waters to the deeper waters and/or sediments. Similar studies are being carried out at stations off the Washington coast. Calanoid copepods which are the dominant zooplankton are widespread throughout the oceans; hence we believe that their fecal pellets will prove to be a major transporting agent in numerous other oceanic areas. (Carpenter [Bennett, Prahl])

Sedimentological studies: In a series of experiments designed to determine whether the contaminants that reach the sediments will remain there or will be remobilized and flux back into the overlying water, chemical fluxes across the sediment-seawater interface were measured with the bell jar method developed here. No significant flux of arsenic from contaminated coastal sediment occurs. We observed greater fluxes of mercury into overlying anoxic waters than into oxygenated waters.

Much higher fluxes of  $^{210}\text{Pb}$  to the sediments were found off the Washington shelf and slope than have been reported off the east coast of the United States by the Yale group. As the fluxes are also higher than estimates of  $^{210}\text{Pb}$  fluxes from the air locally and from the Columbia River, it is currently hypothesized that the high fluxes are due to upwelling off the coast. This hypothesis will be tested during the autumn cruise to the Quinault Canyon region. (Carpenter, Peterson [Bennett])

#### *Carbon Fluxes in Lake Washington*

A study of the carbon cycle of Lake Washington, Seattle, Washington, is being carried out for a 24-month period to quantify the important fluxes and biological transformations that control the carbon budget of the lake. The distribution of DIC and its  $\text{C}^{12}/\text{C}^{13}$  ratio in the lake is monitored as a function of time; the results will be applied to a lake model to derive quantitative information about the varied processes that control the carbon distribution. We will then evaluate independently as many fluxes as possible (air-water, sediment-water, primary production). By these means an estimate of the comparability will be derived, and hence reliability of the whole-lake mass balance and individual flux approaches to biogeochemical problems will be ascertained. This is fundamental to the investigation of any natural system, because it is necessary to determine whether geochemical and biological rates measured over small-space and time-scales accurately represent the whole system.

Analyses of monthly profiles in the water column of Lake Washington for temperature; the radioactive gas radon-222; the carbonate system parameters total  $\text{CO}_2$ , alkalinity, and pH; and the stable isotopes carbon

12 and carbon 13 of the dissolved carbon have been completed. The data are presently being incorporated into a whole lake model to determine the sources and sinks of carbon in the lake. (Emerson, Quay)

#### *Effect of Redox Reactions on Marine Chemistry*

A study of the water chemistry in an intermittently anoxic fjord, Saanich Inlet, British Columbia, is focusing on processes occurring at the oxygen-hydrogen sulfide interface. Particular emphasis is given to the investigation of the predominantly organic matter-manganese oxide particulate layer that forms at the  $O_2$ - $H_2S$  boundary and its effect on the trace species chemistry of the water column. The goal of this study is to derive information about organic matter degradation reactions, the kinetics of inorganic oxidation reactions, the solubility of the transition metals and trace isotopes in oxygenated and sulfide containing waters, and the incorporation of these trace species into the manganese oxide-rich particulate layer.

Samples were collected on two cruises to Saanich Inlet in 1979. Analyses of the chemistry of the water across the oxygen-hydrogen sulfide interface show that the trace metals copper and cadmium are removed from solution in the anoxic waters, nickel is unchanged, and manganese and iron are enriched. Reduced manganese and iron diffuse into the oxygenated waters and are oxidized above the  $O_2$ - $H_2S$  boundary. The oxidation of manganese is bacterially catalyzed and occurs with a time constant of a few days. (Emerson, Kalhorn)

#### *Diagenesis in Marine Sediments*

A multifaceted sampling analytical approach is being used to

study the diagenesis of organic matter and trace metals in the interstitial water of marine and freshwater sediments. Samples collected with an in situ interstitial water sampler are combined with samples obtained by centrifuging sediments from cores. This approach is unique in that analyses of the gases ( $O_2$ , Ar,  $N_2$ ,  $CO_2$ ,  $CH_4$ , and  $H_2S$ ) are combined with those of nutrients, alkalinity, and major ions (Ca, Mg), and pH.

Samples have been collected recently from Lake Washington and from Saanich Inlet and Princess Louisa Inlet in British Columbia for a detailed study of the chemical processes of sulfate reduction and methane fermentation. During November 1981 we will conduct a cruise from Tahiti to the East Pacific Rise at 15°S; our investigations will concentrate on the carbonate chemistry and results of early diagenesis in sediments on the flanks of the crest of the ridge. (Murray [Sawlan, Kuivila]; V. Grundmanis, Hawaii Loa College)

#### *Manganese Nodule Program*

The objective of MANOP, a multi-institutional program, is a detailed study of the influx, remobilization, and final deposition of transition metals supplied by the deep-sea floor of the central eastern Pacific. Remote observations and experiments at the sea floor using bottom ocean monitors (BOMS) have been conducted.

Diagenesis and diffusion in interstitial waters: The results of the 1977 MANOP cruise to two areas (M and H) leave no doubt about the value of pore water chemistry for determining the state of oxidation of sediments in which manganese nodules grow and the flux within interstitial waters of manganese and other metals. The pore water group

has undertaken the task of developing the sampling and analytical procedures for interstitial water analyses. The following methods have been employed: squeezing, centrifuging (intercalibrated with the harpoon of Dr. Murray), and using a newly developed instrument, the peeper, a free-fall vehicle and a closeable peep.

Analyses of the pore water chemistry at four sites in the deep Pacific of differing sediment chemistry (siliceous and carbonate oozes, metaliferous and hemipelagic sediments) have been completed. We have focused on the carbonate system parameters alkalinity, total  $\text{CO}_2$ , and pH. A model using total alkalinity as a master variable has been developed to investigate the processes of organic matter diagenesis and calcite resaturation in the sediments. The ultimate goal of our research is to be able to interpret the benthic fluxes of these constituents and the effect of pore waters on the chemistry of the oceans. (Emerson, [Jacobs, Jahnke])

Adsorption experiments: The hypothesis that inorganic adsorption metal ions on metal oxides is an important mechanism of incorporation and enrichment of these metals into ferromanganese nodules is being tested. Our approach to this problem is two-fold. In situ adsorption/mineral exposure experiments are being conducted in cooperation with Dr. R. G. Burns (MIT) and Dr. P. G. Brewer (WHOI). To supplement these field measurements, we are investigating the extent of metal adsorption in controlled experiments in the laboratory. Besides answering basic questions about the adsorption affinity of different solids, these experiments will provide us with a predictive basis for designing in situ experiments.

A model has been developed that applies the concepts learned from modeling model compounds in the laboratory to natural marine particulate matter. Using this approach we have reached the conclusion that the adsorption behavior of natural marine particulate matter is controlled by organic compounds.

Future studies will be concerned with the trace metal geochemistry of the surface fluff layer at the sediment-water interface. Samples will be collected using R/V *Alvin*. (Murray, Balistrieri)

#### *Composition of Marine Humic Substances*

Humic substances are brown, nitrogenous polymers of variable molecular weight that compose the bulk of the organic matter occurring in soils, sediments, and natural waters. Terrestrial humic acids are formed primarily from the condensation of nitrogenous organic compounds with the phenolic molecules resulting from the microbial degradation of lignins in vascular plants. There is growing evidence, however, that marine humic substances are formed by a different pathway which involves the condensation of nitrogenous compounds with carbohydrates to form polymers known as melanoidins. The hypothesis that melanoidins comprise a major portion of marine humic substances will be tested by structural analyses using  $\text{CuO}$  and alkaline  $\text{KMnO}_4$  degradation reactions. The degradation products of marine and terrestrial humic acids will be compared with each other and with products of synthetic polymers that are hypothesized to correspond in structure. If the melanoidin hypothesis is valid, marine humic acids and synthetic melanoidins should exhibit the following characteristic structural traits: (a) low concentrations of benzene ring units, (b) high levels of oxy-

gen and nitrogen heterocyclic rings, (c) high structural diversity, and (d) low concentrations of lignin-derived structural units.

Results to date of a test of the melanoidin hypothesis by structural analyses using CuO degradation reactions indicate basic differences in the bulk chemical properties of natural marine and terrestrial humic substances. Marine humic substances are apparently more aliphatic in nature as indicated by higher H/C atomic ratios and stronger absorbance of methyl-bonded hydrogens in their IR spectra. The marine polymers are also typically enriched in nitrogen and Carbon-13 compared to terrestrial counterparts. Marine humic acids produce relatively low concentrations of lignin-derived phenols obtained from cupric oxide oxidation. Total yields of lignin-derived phenols from terrestrial humic acids vary widely--from low values comparable to those found for the marine samples to values approximately an order-of-magnitude higher. Analyses of KMnO<sub>4</sub> oxidation products are now in process. (Hedges [Ertel])

#### *Lignin Geochemistry of Quaternary Sediment Cores*

Investigations of land-derived organic matter in sedimentary deposits are continuing. Lignin compounds are being used as indicators of vascular plant remains in cores of Quaternary sediments from the Washington area. In addition, representative lignin source materials, such as vascular plant tissues and Columbia River sediments, are being characterized, and stability of lignins in marine and lacustrine sediments is being determined. Lignins in sediments and plants are determined by high temperature oxidation with cupric oxide to produce mixtures of phenols which are analyzed by gas-liquid chromatography.

Sediments from the Washington continental shelf and slope, and from the Columbia River have now been analyzed. A new method for identifying woody and nonwoody tissues of angiosperm and gymnosperm plants, based upon their characteristic production of different types of lignin-derived phenols, has been worked out. Using these compositional relationships it has been possible to define a lignin-rich band of sediments occurring along the mid-continental shelf off Washington. The lignins in these deposits are primarily derived from gymnosperm woods and nonwoody angiosperm tissues and are chemically stable for time periods of hundreds of years.

Lignin compositions of sediments collected behind dams in the Columbia River drainage basin reflect local vegetation patterns. Lignin concentrations vary widely suggesting a significant input of organic material from sources other than vascular plants. Preliminary results suggest that hydrodynamic sorting of lignin-bearing particulate materials may affect sedimentary compositions.

The lignin content of a ten-meter sediment core from Lake Washington is now being determined with the goal of comparing lignin and pollen compositional changes since the last glacial period. (Hedges [Ertel, Mann, Van Geen]; H. Turin, Princeton University)

## GEOLOGICAL AND GEOPHYSICAL OCEANOGRAPHY

### *Sediment Transport in the Columbia River Estuary*

Investigations of sedimentation in the Columbia River Estuary are being carried out as part of a large multidisciplinary Columbia River Estuary Data Development Program. (See also p. 9.) Through most of the year, sediments accumulate at the mouths of tributaries, in the river channels and estuary, and near the entrance. Each year there is a net gain in sediment storage in the river until eventually sediment is discharged directly into the littoral zone. Although the accumulation of sediment in the lower river increases with time, the locations of deposits change as both the river and tidal flows abandon or occupy new channels on the flood plain and tidal flats. With better understanding of the estuarine system, it will be possible to predict the effects of further alteration of the estuarine configuration. This will involve determination of the complex sedimentological processes that are active in the estuary, including sediment distribution, sediment sources, transport processes, and depositional processes. With these parameters defined, the nature and stability of the sediments can be determined. A knowledge of these processes is also critical in understanding and predicting interactions and activities of the benthic fauna.

The studies are expected to extend over a five-year period (with major field studies during the first three years). They will include: (1) detailed and comprehensive documentation of the pattern of sediment distribution in the estuary; (2) determination of changes in the pattern of sedimentation both on a seasonal scale and on scales of 10's and 100's of years; (3) determina-

tion of the sedimentary history and variations in sedimentary environments in the estuary; (4) estimation of sedimentation rates and sediment budgets for the estuary; (5) definition of sediment transport paths into the estuary, within the estuary, and out from the entrance; and (6) calculation of sediment volumes involved in active sedimentation processes in the estuary. (Creager, McManus, Sternberg, Stewart [Gelfenbaum, Roy, Sherwood])

### *Sediment Transport in the Nearshore Environment*

An in situ field program to determine the nature and relative importance of suspended sediment in the overall long-shore transport process is underway. In the initial phase, the U.W. Sediment Dynamics Group successively evaluated sediment sensing and sampling instrumentation and methodology. A prototype integrated system comprised of various electronic sensors and mechanical samplers for obtaining time-series suspended sediment data in the surf zone was constructed. Field testing and calibration have been accomplished both locally and in conjunction with Scripps Institution of Oceanography and the Naval Postgraduate School.

During the past year field studies using these instruments were carried out at Twin Harbors, Washington, and at Ledbetter, Santa Barbara, California. Continuous observations were made of suspended sediment concentrations within the surf zone over a range of wave conditions. The data are being analyzed to determine the relationship of sediment suspension to flow conditions, the spatial distribution of suspended sediment within the surf zone, and total and net longshore transport of sediment. (Sternberg, Lister [Downing])

*Joint U.S./China Investigation of  
Marine Sediment Dynamics*

A cooperative research effort has been initiated between NOAA and the National Bureau of Oceanography of the People's Republic of China. In addition to NOAA and Chinese scientists, scientists from several academic institutions in the United States are participating. The objectives of this research are to investigate the movement and accumulation of sediment (both at present and during the Holocene) within the Yangtze River estuary and on the adjacent continental shelf. Specific areas of investigation include measurements of the current regime, hydrographic character (temperature, salinity, suspended matter) of the shelf, seafloor morphology and shallow stratigraphy, substrate sampling for benthic biology, chemistry, and geology/geotechnics. A preliminary cruise using one NOAA and two Chinese research vessels was carried out in June-July 1980.

The specific objectives of the project with which we are involved are to determine the character of the bottom currents and the associated sediment response at selected locations on the continental shelf of the East China Sea. Measurements are made with an instrumented tripod, which was deployed at 50 m depth off the mouth of the Yangtze River for a 30-day period. Measurements include mean currents 1 m and 2.3 m off the seabed, tidal fluctuations, and wave activity. Observations of water turbidity (nephelometer), bottom photography, and limited suspended sampling also were carried out. The data will be analyzed to determine the effects of bottom currents, tidal currents, and surface gravity waves in the transport of sediment in that area. (Sternberg, L. H. Larsen)

*A Pacific Northwest Paleomagnetic  
Instrumentation Consortium*

A Paleomagnetic Instrumentation Consortium has been established at the University of Washington. The consortium consists primarily, but not exclusively, of University of Alaska, Oregon State University, Western Washington University, and University of Washington scientists who are engaged in paleomagnetic and rock magnetic studies. The basic instruments used by the consortium members are a three-axis superconducting magnetometer and associated computer system, two demagnetizing units, a vibrating sample magnetometer, a viscous remanence magnetometer, and an eight-foot, three-axis Helmholtz frame for thermal demagnetization. This state-of-the-art equipment is housed at the Oceanography Department, University of Washington. The quantity and scope of Pacific Northwest paleomagnetic and rock magnetic research are greatly enhanced by the availability of this Instrumentation Consortium. (H.P. Johnson, Merrill)

*Paleomagnetic, Rock Magnetic, and  
Opaque Mineralogy Studies of an  
Eastern Iceland Drill Core*

The Iceland Drilling Project--a consortium of scientists from several countries--was responsible for drilling a two-kilometer deep completely cored hole in Eastern Iceland during the summer of 1978. (See also p. 26.) Papers on the many research projects concerned with this drill core will appear in a dedicated issue of the *Journal of Geophysical Research*.

Currently, we are studying the effects of burial metamorphism, contact metamorphism, and low temperature oxidation on the magnetic properties of samples from the core. Preliminary paleomagnetic data show that three magnetic polarity units

are present in the drill core, consistent with the radiometric ages of associated rock units. Detailed rock magnetic and opaque mineralogy studies show that the deeper parts of the drill core are extremely remagnetized, probably by contact with circulating hydrothermal fluids. (H.P. Johnson, Merrill)

*Paleomagnetic Input into Dynamo Models for the Earth's Magnetic Field*

Cooperative work with the Australian National University on long-term anomalies in the time-averaged paleomagnetic field and on geomagnetic secular variation is continuing. Analyses using 266 land-based points [each "point" represents a considerable amount of data] and 100 deep-sea cores, all with ages less than five million years, clearly indicate that the time-averaged field is not simply a geocentric axial dipole field as is assumed in paleomagnetism. Moreover, the analyses show that there are significant differences for normal and reversed polarity times.

These results are surprising as it can be shown by considering magnetic induction and Navier-Stokes equations, which are fundamental to dynamo theories, that either state has equal probability of occurring. Speculations on how this problem might be resolved have been given, but so far none of these appear very convincing. (Merrill; M. W. McElhinney, Australian National Museum)

*Rock Magnetism of Pacific Ocean Deep-Sea Cores*

A two-pronged magnetic and geochemical study of several deep-sea cores from the Pacific Ocean is continuing. Rock magnetic studies are combined with geochemical studies, including neutron activation analy-

ses and atomic adsorption analyses, to delineate the origin and alteration of the magnetic minerals. Particular attention is given to identifying erroneous paleomagnetic signatures, to obtaining reliable paleomagnetic results from cores previously judged to be unreliable, and to using rock magnetics for a better understanding of the overall geochemical environments in deep-sea sediments.

Todorokite forms authigenically in many red clay regions and appears to acquire a chemical remanence that masks the previous remanence. Contrary to previous findings in our laboratory and elsewhere, magnetization appears to have minor effect on changing the directions of the remanence in deep-sea cores. (Merrill, H. P. Johnson [G. Smith])

*Thermal State of Old Oceanic Crust and Lithosphere*

A heat flow measuring instrument has been developed and constructed. It has the capability of an indefinite number of penetrations into the ocean floor without mechanical damage and measures both the thermal gradient in the sediments and the thermal conductivity of the material around the probe. Data are telemetered in real time by a digital acoustic link, and the instrument can be deployed for a full three days by any standard deep-sea winch on the ship. The first test cruise, off Newport, Oregon, produced over two hundred sea-floor thermal gradients and a substantial number of conductivity measurements. A record lowering with 82 penetrations was achieved over 48 hours. Minor bugs in the first version of the instrument were then corrected, and a backup unit built.

The final version of the instrument has been used in a joint shipboard investigation of heat flow

in the subtropical western North Atlantic. Our personnel supervised installation of the instrument on the Woods Hole Oceanographic Institution ship R/V *Knorr* and were available to maintain it on the cruise. A large quantity of high-quality data was obtained at sites carefully selected to represent both a range of age and freedom from local tectonic disturbance. Routine processing of the measurements will be carried out at the Woods Hole Oceanographic Institution and Massachusetts Institute of Technology, but University of Washington personnel expect to be closely involved in the interpretation and publication phase of the project.

An additional investigation of the process of conductivity measurement will be performed locally with the field instrument. Interesting discrepancies have been noted between the temperature curves measured in the field and those expected from the theory and construction of the apparatus. This discovery is due to the uniquely high resolution and accuracy of the new instrument and the attempt we are making to improve the accuracy of heat flow measurement by nearly an order of magnitude. (Lister [Mojesky])

Another part of the study is the determination of the internal heat generation in the thick sediments of the area to calculate a correction to the measured heat flow. Surface cores and DSDP samples will be used and the measurement made with equipment at the Pacific Geoscience Center, Sidney, B. C. (Lister, Davis)

#### *Convection in a Porous Medium at High Rayleigh Number and Its Geothermal Implications*

Experimental and theoretical studies are underway to settle the

problem of heat transfer rates in porous-medium convection. Prior experiments have not modeled a porous medium closely enough to obtain consistent results at Rayleigh numbers more than a few times critical. Determinations of the temperature-and-flow structure in the convecting medium have not had the resolution to detect the development of boundary layers, except for a few experiments done in a two-dimensional Hele Shaw cell. The twofold requirement of reaching a high Rayleigh number in a porous bed and of ensuring that the grain size is smaller than the boundary layers that develop near the heat source and heat sink means that satisfactory experiments can be carried out only in a very large apparatus. Such a large facility will be constructed, and once for all the relationship between heat transport and Rayleigh number will be delineated up to a value of  $10^4$  for the latter.

The project is currently proceeding well but behind schedule due to the departure of the graduate student involved in the design and construction of the laboratory facility. To date an outstanding Master's thesis has been produced, and all the major problems of cell construction and control have been solved. In addition, we have discovered an ideal material--rubberized curled fiber--for the porous medium fill of large convection cells. It has a high permeability, a low thermal conductivity, and less variation in permeability with flow rate than porous media made out of sand or gravel; further, it is light and inexpensive. Characterization of the material has been completed, using a 12-channel labyrinth and pressure heads as low as 5 mils (.005 inches) of water. (Lister [Gibson]; J. R. Booker, Geophysics Program)

### *DSRV Alvin In Situ Investigation of Deep Oceanic Crust*

A series of DSRV *Alvin* dives on the Kane Fracture Zone on the Mid-Atlantic Ridge, where hydrothermal quartz veins were discovered to be common in older oceanic crust exposed by tectonic movements, have been carried out. Detailed studies of these veins will provide important constraints on models of subsurface hydrothermal circulation of seawater through the oceanic crust. (Delaney, H.P. Johnson, W.B. Bryan and G. Thompson, Woods Hole Oceanographic Institution)

### *Volcanic Volatiles*

A multi-institutional investigation on the abundance, distribution, and transport mechanisms of volatiles in high temperature geological systems is underway. The program includes: (1) use of the ion microprobe at Johnson Space Center, Houston, Texas, to perform the first systematic analyses of water in silicate systems using a microbeam technique; (2) collaborative studies with John R. Holloway at Arizona State University to experimentally define diffusion of reaction parameters of volatile migration through silicate melts under subvolcanic conditions; (3) a comprehensive study of the pre-eruption water contents of island arc and oceanic volcanic systems using the ion microprobe to study glass-apor inclusions trapped in phenocrysts which subsequently erupt to the surface. (Delaney [Karsten])

### *Fine Structure of the Oceanic Crust*

The principal thrust of this program is

- 1) to determine the detailed compressional and shear wave velocity of the sedimentary, igneous, and meta-

morphic rocks of the oceanic crust and upper mantle;

- 2) to use experimental and theoretical methods to determine the nature of acoustic wave propagation in the lithosphere;
- 3) to determine the structure of the oceanic crust and the processes involved in its formation.

Seismic refraction data taken with ocean bottom seismometers and a deep-towed array during the ROSE experiment are being analyzed in terms of the structure of the East Pacific Rise at 12°N and the change in crustal and upper mantle velocities with age. To improve the quality of the interpretation of the seismic data, theoretical work is being done on wave propagation in laterally heterogeneous media and radon transform techniques for inverting the data. The analysis will be greatly facilitated by the recent acquisition of a new multiusers computer system. (Lewis, Christensen, Garmany [Wong, Tuthill, Hegdahl])

### *Generation and Evolution of the Oceanic Crust*

The processes of lithospheric generation and consumption are being investigated, using the Juan de Fuca, North America, and Pacific plates as the study area. (See also p. 26.) Refraction, reflection, and magnetic studies have been undertaken on the Juan de Fuca Ridge, the central part of the Juan de Fuca plate, and on the Washington margin in the area of Grays Harbor; a land refraction line was run in the coastal zone. Results to date indicate the presence of a ridge crest that is typical of a fast spreading situation and is probably influenced by the Juan de Fuca hot spot. The cen-

tral part of the Juan de Fuca plate has normal oceanic crust overlain by up to 2 km of sediment. At the margin these sediments appear to be scraped off the underthrust plate and accreted to the Washington margin by folding and faulting. A typical trench morphology appears to be buried by the thick pile of sediments.

Future work on this project will involve data analysis, numerical modeling, and a few short field trips to refine the results. (Lewis, Garmany [McClain, Tabor]; S. W. Smith, Geophysics Program)

#### *Hot Spot-Ridge Crest-Fracture Zone Dynamics*

Magnetics, geochemical, and seismic studies of the southern Juan de Fuca and northern Gorda ridge crests and the segment of the intervening Blanco fracture zone are being investigated. (See also p. 25.) The purpose of this project is to examine the processes associated with oceanic crustal formation in a zone of interaction of a ridge crest with a hot spot or deep mantle plume, the southern Juan de Fuca ridge, and to compare them with processes associated with a different type of ridge crest formation at the Gorda Ridge. We propose to examine the hypothesis of longitudinal magma flow along a ridge crest and to study the source of the high amplitude magnetic anomalies associated with the southern Juan de Fuca crest. Closely-spaced dredging to obtain rocks for detailed magnetic and geochemical studies, reflection profiling, a surface-towed magnetometer, and a deep-towed underwater camera system were used on this project. Data were obtained on a 31-day cruise aboard the R/V *Thomas G. Thompson* during August 1980. (H.P. Johnson, Delaney, Lewis)

#### *ONR Refraction Experiment*

This project is now limited to the reduction and interpretation of ocean-bottom seismometer data obtained in an experiment conducted in 1974 off the Queen Charlotte Islands. Conceptually, considerable progress has been made, and the field laboratory data may come closer to achieving the original goals of the joint OBS-laboratory project than was originally expected. In testing whether the orientation of the horizontal seismometers could be obtained from water-wave arrivals, we have found that they can be oriented  $5^\circ$ . This means that 3-component record sections can be expressed in true radial and transverse components. The importance of this can be seen with reference to recent work by Crampin (1977). He has shown that the polarisation of S-waves in rocks is extremely sensitive to elastic anisotropy since phenomena similar to those in optical wave-retardation plates can occur. The presence of significant transverse S-wave energy would be a convincing proof of shear-wave anisotropy in the oceanic crust, and we are looking forward to testing this hypothesis. (Lister [Wade])

#### *Seismic Properties of the Upper Iceland Crust*

An integrated geophysical study of the acoustic properties of the Iceland crust near the Reydarfjordur drilling site is being carried out. (See also p. 22.) During the summer of 1978, as part of an international project designed to continuously core up to 2 km of Iceland crust in southeast Iceland, three closely related projects were initiated: (1) a field study of Icelandic crustal structure in the vicinity of the drilling site, (2) a downhole logging program which included seismic logging, and (3) a carefully

controlled sampling program for laboratory measurements of the acoustic properties of the cored rocks at elevated pressures and temperatures.

The interpretation of the seismic data showed that the increase in velocity is gradational in the upper 3 km but becomes rapid below about 3 km. A correlation of these results with the logging and laboratory data suggests that the increase in velocity with depth can be partially attributed to a decreasing porosity and crack density with depth.

One part of this study, the inversion of the seismic data to obtain a velocity depth distribution for the upper Icelandic crust, has been used for a Master's thesis. (Lewis, Christensen [Thompson])

#### *Puget Sound Lowland Seismic Activity*

This project was begun in February 1980. Much of the historical and potentially damaging seismic activity in the Puget Sound Lowland is geographically related to the Seattle gravity gradient and the block or blocks along its southern margin. Conflicting structural interpretations, arrived at from surface geology, land gravity, and seismic reflection profiles, can be resolved by the use of marine refraction and gravity and rock density and velocity analyses (laboratory) to constrain the interpretive models. Refined gravity mapping is especially critical in water-covered areas so that limits may be placed on interpretations of known or hypothesized major faults in the Seattle-Tacoma area.

Marine refraction, reflection, and gravity data will be collected to permit improved modeling of the large amplitude (80 milligal), but short wave length, Seattle (Bouguer) gravity minimum. The area between Seattle and Tacoma will then be stu-

died using similar techniques. Long (11km) reversed refraction lines will be obtained along the Puget Sound axis, and transverse lines will be shot at carefully selected locations. Combined marine and land gravity observations will be made to locally upgrade existing maps in critical places. Seismic reflection (air gun) data will be obtained on all tracklines. Outcrop samples will be collected for rock density and velocity analyses. All available geological and geophysical data will be used to test three-dimensional geologic/tectonic models. (Holmes, McCulloh, Lewis; R. S. Crosson, Geophysics Program)

## PHYSICAL OCEANOGRAPHY

*Model Studies of the Ocean-Atmosphere System*

Basic model studies of steady oceanic circulation: A simple three-dimensional model is used with a vertically uniform mixed layer, an ideal fluid interior, and a parameterized western boundary current. Solutions forced by given wind stress and differential surface heating are obtained by integrating along selected characteristics of the model. A main result is the appearance of fronts in the model, requiring that the classical similarity assumption for the oceanic thermocline be abandoned.

Research on other problems in the same general area has been carried out jointly with scientists at the Max-Planck Institute for Meteorology, Hamburg, and at the Geophysical Institute, University of Bergen. (Welander)

Energy-balanced global climate model: The model includes effects of land and sea ice and represents a generalization of the theory of Budyko and North. A main result is the stabilizing effect of the oceans when the solar constant is varied. (Welander [Liu])

Large-scale oceanic thermal dynamics: Theoretical model studies of an idealized ocean forced by atmospheric differential heating have been undertaken. The simplest model is a vertical well-stirred layer with given horizontal advection; another is a three-dimensional model with a mixed layer on top of an ideal thermocline and a "frozen" velocity field. A main result is the non-existence of any significant "thermal memory" in these models; typically less than a per mille of a large-scale thermal disturbance is

"remembered" after passing the interior.

A second part of this work comprises thermally interacting well-mixed boxes representing a time-variable atmosphere, as well as oceans due to strong nonlinear interaction; such systems show a time development which masks the signatures of driving forces. A general conclusion from this is that causes of climatic fluctuations are difficult to trace from observed records of climate variables. Two reports on these studies have been submitted for publication. (Welander)

*Predictability of the Atmosphere*

Theoretical predictability of the atmosphere, assuming a perfect dynamical model, is limited by the time over which uncertainty in initial data is transferred by nonlinear processes into all predicted scales of motion. Actual prediction skill is further limited by inadequacies in the formulation of physical-numerical models. We will consider both questions, seeking (1) to refine theoretical estimates of ideal predictability and (2) to identify a possible source of loss in prediction skill. The predictability study will follow the turbulence closure theoretical approach of Leith (1971), here extended to include effects of planetary wave propagation. Questions of prediction skill will focus on possible effects of wave-wave interaction on phase and group speeds of planetary waves. A third area of investigation will concern possible specific configurations of an atmosphere that might be predictable over an anomalously long time in the sense of persistent finite amplitude solutions of model equations.

Programs for high resolution computer simulation of interacting planetary waves have been developed and verified. Initial experiments have examined "frequency smearing" due to nonlinear interactions. A theory has been developed to describe this "smearing." (Holloway, Dworski, Davey [Donahue])

#### *Studies of Finite Amplitude Waves*

Studies of the modulation patterns and modulation scales of surface waves in the ocean involve three main topics: sea-level variations associated with the passage of a wave packet, numerical modeling of a wave system that self-modulates, and examination of imaging radar data.

Observations of sea-level variations at a Washington continental shelf site removed from immediate coastal effects show minimal correlation with those predicted by plane wave radiation stress arguments. Since these arguments are often used in engineering applications, a lack of observed correlation between low sea level and high waves has an immediate impact on wave force calculations. Radar images offer a view of the sea surface that shows modulation patterns. We wish to determine if modulation patterns do relate to wave slope as is predicted by wave interaction models. The numerical studies provide guidance in interpretation of the observations. (Larsen [Shi])

#### *Geostrophic Transport and Water Characteristics of the Central Pacific Equatorial Current System*

As part of the NORPAX program to study the low-frequency variability of the central Pacific equatorial current system, a series of 48 meridional CTD sections was made between 21°N and 17°S during the First CARP Global Experiment (FCGE)

in 1979 and the first four months of 1980. The oceanographic measurements suggest that during the first year no major perturbations of the current system occurred so that a typical seasonal variation of the system was observed. Cyclonic eddies (300 km diameter) were observed in the North Equatorial Current, but no strong eddies were found in the South Equatorial Current. The South Equatorial Current shows the greatest variation during the year in geostrophic transport. Comparison of zonal geostrophic transports in the North Equatorial Countercurrent at 158°, 153°, and 150°W during a single cruise shows significant longitudinal changes in the transport which implies that there is meridional flux out of the countercurrent and that recycling of the water occurs as water flows eastward. The phase relationship between transport fluctuations of the various components of the system will be documented and compared with simple models of wind-driven equatorial currents. (Taft, Kovala)

#### *Dynamics of Equatorial Waters*

An important aspect of climate is to understand the role of the tropical ocean in influencing the long-term behavior of the atmosphere. Evidence for the global impact of tropical sea surface temperature (SST) variations comes from studies of atmospheric general circulation models. In these it is found that tropical SST anomalies, imposed as lower boundary conditions, are more effective than mid-latitude anomalies at inducing persistent anomalies of atmospheric circulation. There is considerable statistical evidence that fluctuations in the transports of the major zonal currents in the tropical Pacific cause varying heat fluxes into the eastern tropical region and hence cause SST variations there.

Surface wind and upper ocean current and temperature observations have been recorded in diamond-shaped and/or triangular surface mooring arrays placed near  $0^{\circ}$ ,  $152^{\circ}\text{W}$  and  $0^{\circ}$ ,  $110^{\circ}\text{W}$ . These data provide insights into the coherent time and space scales between the wind and the upper ocean currents and heat transport. In addition, the adjustment of the zonal thermocline along the equator has been studied by means of temperature profiles. These measurement programs are components of NORPAX and EPOCS. (Halpern)

Sea-level measurements are currently being made near the equator (Galapagos Islands). Measured equatorial wind stress and a simple free wave model will be used to try to explain these observations. Short-term tropical climate fluctuations seem to be related to sea-surface temperature fluctuations and sea level so the proposed analysis will be a first step in an anticipated study of coupled ocean-atmospheric motions. (Clarke, Hayes)

#### *Arctic Sea-Air Interaction*

Investigations designed to quantitatively understand the way in which the ocean and atmosphere interact in polar regions are continuing. In the past year, the following studies have been carried out in investigations of those areas where classical fluid mechanics is of importance to Arctic processes: field and laboratory studies of the melting of icebergs in seawater, a laboratory study of sea ice growth in a wave field, and, in cooperation with the Scott Polar Research Institute, a field study of ocean swell propagation into pack ice in the Bering Sea. (Martin, Kauffman [Bauer]; G. A. Maykut, Department of Atmospheric Sciences)

#### *Bering Sea Ice Studies*

The Scanning Multi-Channel Microwave Radiometer (SMMR) on board the NIMBUS-7 satellite is being used in this study. In cooperation with the Goddard Space Flight Center and the Pacific Marine Environmental Laboratory, the ice properties measured by the satellite are being compared with those measured during our March 1979 ice edge cruises on the NOAA ship *Surveyor*. The combined data will be used to verify the Goddard sea ice algorithm which then will be used with future satellites. (Martin, Kauffman)

The flexure response of ice floes to incident ocean swell is being studied, using data from the 1979 Bering Sea ice edge cruise. (Martin; V. Squire, University of Cambridge)

#### *International Southern Ocean Studies*

ISOS, a multiinstitutional program, is a series of dynamics and monitoring experiments in the Southern Ocean, primarily in Drake Passage and the region southwest of New Zealand. The objective is the understanding of the long-term, large-scale variability of oceanic processes and the interaction of the Southern Ocean with the global oceanic and atmospheric circulation.

The major part of the field program ended in early 1980, with the recovery of a major array of current meters, temperature/pressure gauges, thermistor strings, and bottom pressure gauges from the Drake Passage region. A five-year data set is available. During 1979-80, the array operated simultaneously with the Global Weather Experiment, which will provide accurate winds and wind stress over the southern hemisphere for a period of 14 months -- the first time that synop-

tic data have been available in this region.

We have concentrated primarily on analysis of the data from the bottom pressure gauges, especially on their relation to the winds. Two papers now in press document the reliability of the instrumentation and the fluctuations in average transport through the passage. Our work has shown for the first time the strong correlation between the transport and the wind and has demonstrated a response time of the order of a week for this major current.

Continuing studies include analysis of the data from the major 1979 array and their relation to the wind, analysis of data on currents and temperatures from the entire Southern Ocean region from the set of drifting buoys deployed as part of the Global Weather Experiment, and additional tests of the instrumentation involved. Plans are also moving ahead for the establishment of a major network of sea level gauges in the entire Southern Ocean region as part of international plans for monitoring the global ocean circulation and its role in climate. (Baker [Larson]; R. B. Wearn, E. J. Krause, A. M. Pederson, Applied Physics Laboratory)

#### *Diagnostic Determination of Low Frequency Currents in the Southern Ocean*

The effects of large-scale bathymetric relief on the mean ocean circulation are being investigated. Since this relief is felt by the bottom currents it strongly controls the deep circulation and thus the rate of renewal of deep water concentrations. A diagnostic calculation is being carried out on the Southern Ocean utilizing observed hydrographic data and sea surface

pressure fields to obtain the three dimensional velocity field. From the resulting flow field we will obtain and assess the role of the topographically controlled standing waves in the momentum and vorticity budgets. As a contribution to the climate problems, we expect also to infer the meridional heat flux distribution in this ocean. (Rattray, Dworski)

In another climate-related study, a simple, iterative, steady-state model, in which the western boundary current is constrained to flow over shallow bathymetry, is being developed. It is hypothesized that restricting the return flow to shallow depths in the western boundary of a subtropical gyre will augment the meridional heat flux over that in an ocean without such a depth restriction to the flow. (Rattray, Dworski [Shetye])

#### *Dynamic Analysis of the Eddy Field*

During the summer of 1978 a two-month program of CTD profiling (POLYMODE Local Dynamics Experiment) was conducted over a 200-km square region southwest of Bermuda to measure the variability of the temperature, salinity, dissolved oxygen, and density fields. The density data will be combined with velocity data from moorings and SOFAR floats to construct the stream function for the geostrophic flow field. A dynamical analysis of the evolution of the mesoscale eddy field will be undertaken using the quasi-geostrophic potential vorticity equation. Work to date has concentrated on preparing the cast data for analysis and compositing with the velocity data. A striking feature of the data set is the occurrence of at least three small-scale (25-50 km) features with strong oxygen and salinity anomalies, high ratios of kinetic to potential energy, and vertical scales of 400 to 2,000 m. These features

may be traced to their most likely source region by comparison of their properties with the large-scale North Atlantic water mass distribution. These comparisons suggest that the features contain water characteristically found in distant locations such as the Labrador Sea and the tropical Atlantic and that it has propagated with very low rates of mixing. Consideration is being given to processes that could account for such effective water mass isolation. Models of Rossby wave interference patterns have been shown to be a possible water mass trapping mechanism. (Taft, Shen [Lindstrom]; J. C. McWilliams, National Center for Atmospheric Research)

#### *Arctic Ocean Circulation Studies*

Our long-term objective is to describe and understand the thermo-haline and wind-driven circulations of the various arctic seas. At present our attention is centered on mechanisms related to climate (e.g., lateral and vertical transport of heat and salt), on the hydrographic structure, and on the deep circulation.

Polar Basin: The recent deployment and recovery of current meter moorings on the crest and flank of the Lomonosov Ridge, close to the North Pole, is a major accomplishment. This is the first use of bottom-moored instruments in the Polar Basin, and it opens up a whole new set of experimental possibilities in ice-covered areas. The measurements show that the deep waters cross the Lomonosov Ridge. The overflow moves diagonally up the ridge in a pulsating manner, with peak speeds exceeding  $12 \text{ cm sec}^{-1}$ . There are indications that oscillations with periods exceeding about two days are bottom-trapped. Flow in the abyss is generally less than  $1 \text{ cm sec}^{-1}$ , but more energetic epi-

sodes with speeds of  $2\text{-}4 \text{ cm sec}^{-1}$  occur, typically 5-10 days apart.

Other fieldwork included a late-winter ice breaker cruise in the Greenland Sea to elucidate the mechanisms responsible for the formation of bottom water. (Aagaard, Darnall, Harding, Tripp [Hanzlick, Sayles])

West Spitsbergen Current: About two-thirds of the oceanic heat flux into the Arctic Ocean is accomplished by the Atlantic water of the West Spitsbergen Current, an extension of the Norwegian Atlantic current which carries warm saline water northward through the eastern Greenland Sea. Very large variations in this flow at very long time scales (months to years) have been suggested by earlier investigations.

For the past three years moored current and temperature recorders have been deployed at  $79^\circ \text{ N}$  in the West Spitsbergen Current to determine the lateral variability of the current and to provide definition of the low-frequency variability. Analysis to date shows a rich spatial and temporal structure and suggests the existence of a number of trapped wave modes over the slope and shelf.

Analysis of the first year's records yields spatial correlation lengths across the flow of about 35 km to less than 13.5 km. Transport calculated from 14-day current averages during 1976-77 range from 0.6 Sv southward to 8.6 Sv northward, averaging 3.6 Sv northward. Mean annual northward speeds range from  $3.8 - 13.3 \text{ cm sec}^{-1}$ , depending on longitude and year. All records demonstrate prominent tidal signals, while other identifiable signals range to about 60 days. In addition, longer period trends, such as a slight velocity increase and a temperature decrease over the entire

three years, appear at one mooring location. Shears calculated from meter pairs indicate that the flow is mostly barotropic ( 70-85%). However, the shears vary dramatically in time, even changing sign for periods of weeks. (Aagaard, Darnall, Swift, Tripp [Hanzlick])

Beaufort Sea: Investigations of the circulation on the Beaufort Sea shelf and the exchange between the shelf and the deep Arctic Ocean are continuing. A total of 13 Eulerian time series of current and temperature, as well as a number of CTD sections, have been obtained from 1976-1980.

An energetic current regime over the outer shelf extends landward of the 60m isobath. The flow is characterized by a series of pulses, in which the water alternately moves eastward or westward along the isobaths in a reciprocating fashion. The strength of these pulses is typically about  $20 \text{ cm sec}^{-1}$  but can on occasion exceed  $65 \text{ cm sec}^{-1}$ , and their duration varies from a day to several weeks. The eastward pulses are generally stronger and longer lasting. The long-term mean flow is therefore eastward (along the isobaths) and in the range of  $5-10 \text{ cm sec}^{-1}$ . There does not appear to be any seasonal cycle in the flow. These remarks apply to the motion below about 40 m; above this depth, the velocity field is unknown, as the drifting ice makes moored measurement at lesser depths extremely hazardous.

The thermal regime down to at least 65 m is largely advectively controlled, with the water bearing the mark of the freezing process until midsummer. At that time, warm water is advected into the region, probably largely from the Bering Sea, and there are strong horizontal temperature differences. Under these circumstances, waters of dif-

ferent origin being advected past a given point cause a highly variable local temperature regime. Close to the bottom a frequent invasion of warm and saline Atlantic water occurs in a pulse-like manner and extends over large portions of the shelf. During such events the temperature increases to  $1-2^\circ\text{C}$  or more above the freezing point. The pulses occur at all times of the year and have time scales similar to the reciprocating along-shelf motion discussed above. These are in effect upwelling events from 350 m or deeper offshore, and they must bring relatively large amounts of salt and sensible heat onto the shelf.

On the inner shelf, under land-fast ice, the flow in winter appears to be extremely slow. This contrasts with the summer situation when the wind can drive a vigorous circulation in these same waters. (Aagaard, Darnall, Harding, Tripp)

#### Oceanic Variability and Dynamics

The long-range objectives of these studies are to understand the properties of ocean currents and waves, particularly through studies of the vertical structure of velocity and density fields. Emphasis is placed on gaining new insight into the dynamical processes involved in low-frequency eddies and fronts, the influence of the ocean bottom on currents, the generation and dissipation of microstructure, and the propagation of internal and acoustic waves. Our principal observational tool is the electromagnetic velocity profiler (EMVP).

Velocity profiles (POLYMODE XTVP) over and near the Caryn Seamount, an isolated peak rising about 2,000 m above a flat bottom of 5,000 m depth, have been analyzed. Strong inertial motions in the main thermocline that exist over the seamount are seemingly not as a consequence

of generation but due to focusing of internal waves by the time-mean shear of a topographically-trapped eddy.

We are participating in the North Pacific Subtropical Front field program, which includes both station and underway measurements; our component comprises investigations of the energy and vertical structure of the low-frequency and internal wave shears. About 80 expendable velocity profilers will be used:

- 1) to measure low-frequency and internal-wave shears on velocity profiles as a function of distance from, and structure of, the front;
- 2) to obtain a profile time series within the front in order to quantify the temporal structure and statistics of the vertical shear field;
- 3) to relate the shear field over vertical scales of 10-100 m to the finer-scale mixing processes;
- 4) to provide velocity measurements in support of other measurement programs and joint experiments.

We propose to occupy several sites (3 at a minimum), spaced at 0, 5, and 10 km from the front, each consisting of profiles every 5 - 10 minutes for 1 hour. From the measurements of the high-frequency, internal wave motions at several places in and near the front, several statistics such as  $v'T'$  have coherences, and modal structure will be computed. Johnson and Sanford (1979) have used  $v'T'$ , where  $v'$  and  $T'$  are velocity and temperature gradients in the vertical, to determine

the horizontal direction of internal wave energy flux. The velocity-temperature coherence is small except when the internal wave field is anisotropic, consisting of internal wave traveling predominantly in one direction.

With the ship underway profiles along a section normal to the front will be collected. The section should be 20-km long on both sides of the front (40 km total) with profiles every 4 km. The length is based on the expected scale for the frontal shear (i.e., the local radius of deformation), and the repetition interval results from the desire to measure at scales smaller than the expected 10-km correlation length for the internal wves.

This section will be repeated at least twice at 6-hour intervals (i.e., 0, 6, and 12 hr.). From this crude or gappy time series the low-frequency (time-mean) shear and inertial-internal waves can be estimated. The principal purpose of this aspect of the work is to collect a synoptic data set of temperature and velocity observations from a ship underway. (Sanford)

#### *Oceanic Fronts in the Western North Pacific*

Variability of sea surface temperature fronts in the western North Pacific is investigated using satellite and shipboard data. On a 100 km by 100 km grid and a time step of a week, the satellite recognized the subarctic front, the subtropical front, and one or two fronts associated with the Kuroshio intrusion. The subarctic front is centered near 42°N and can be seen throughout the year. Frontal gradients vary between 2-5°C/100km and deviations of frontal position from the mean latitude are small. The subtropical front is seen only from late fall to early summer, between 28° and 35°N,

with maximum gradients of  $3^{\circ}\text{C}/100\text{ km}$ . Kuroshio fronts occur sporadically between  $35^{\circ}$  and  $37^{\circ}\text{N}$  and are not well resolved on  $100\text{ km}$  scales. The findings by satellite are in agreement with those derived from shipboard observations employing a similar sampling scheme. (Roden)

Oceanic fronts in the subtropical frontal zone are related to atmospheric forcing. The frontal zone is marked by the presence of multiple fronts. In the upper  $100\text{ m}$ , the temperature and salinity fronts are largely density compensating and almost vertical. A high stability layer is observed between  $100$  and  $150\text{ m}$ . Beneath it, there are prominent intrusions of cold and low salinity water. The observed features suggest dominance of Ekman dynamics with attendant northward flow in the upper layer and dominance of geostrophic motion with southeastward blow beneath the pycnocline. Upper layer fronts are formed predominantly by convergence and deformation of the Ekman flow, while lower layer fronts form primarily in response to geostrophic deformation and differential vertical advection. It was found that for a given configuration of the Ekman flow field, the intensity of thermohaline frontogenesis depends on the initial horizontal thermohaline stratification and the persistence of the particular Ekman flow field. After atmospheric forcing ceases, fronts do not decay instantly but continue to persist for some time. Thus, at any given instant, "live" as well as "fossil" fronts are found in the ocean, complicating the interpretation of observations. (Roden)

#### *Oceanic Boundary Layers*

Linear fluctuation theory is proposed for theoretically studying the structure and maintenance of unsteady motions within the turbulent Ekman boundary layer with applica-

tions intended for understanding behavior of both upper and bottom geophysical boundary layers. In addition, establishment of the general stability characteristics for laminar Ekman layers will be made so that specific initial-value problems can be investigated.

Fluctuations in the Ekman oceanic boundary layers are investigated theoretically under both laminar and turbulent mean flow conditions. Basically, an understanding of the structure and the mechanisms that are needed to maintain such flow are sought. Successful results have been achieved by combining linear analyses with numerical computations together with specific problems modeled by the underlying physics that are necessary to describe the physics. Both quantitative and qualitative evaluations are presented (Criminale [Spooner])

Linear (coupled with ultimate nonlinear considerations) analysis, together with numerical methods for solution, is to be used for investigating fluctuations in (a) stratified shear flows and (b) laminar boundary layers. In particular, complete solutions for initial-value problems in a modeled geophysical environment are to be considered by use of Laplace transforms; spatial Laplace integral techniques are to be employed for probing new types of temporal solutions for both types of problems. A dual perturbation problem is to be examined for rigorous treatment of boundary layer oscillations. (Criminale [Bradt, Spooner]; J. Kevorkian, C.E. Pearson, Applied Mathematics Group)

#### *Mixing Processes*

The long-range objective of this continuing research is to develop a quantitative understanding of the dissipative processes in the ocean and their role in the large-

scale, time-averaged budgets of heat, salt, and momentum. To achieve this it is necessary to observe microscale fluctuations of temperature, salinity, and velocity to scales less than a centimeter and to relate the dissipative structures to fine scale variability occurring over scales of from a meter to about 10 kilometers. Since these same variables also determine the velocity of sound, some of the processes and structures observed are major factors causing acoustic fluctuations in frequency bands of practical importance to the Navy.

In following the above approach, it has been learned that thermohaline intrusions and internal waves are the major links between the dissipative processes and large or mesoscale phenomena. Accordingly, the focus of these studies has been broadened to study the intermediate scales in their own right and not just as background for the microstructure.

The work that has been done to date includes: intensive design effort on the Multi-Scale Profiler (MSP), improvements in the electrical design of small-scale conductivity probes; re-analysis of the MILE temperature microstructure data using new thermistor response curves, and additional analysis of the separation between reversible and irreversible finestructure. Continuing studies include: work on small conductivity cells, a significant increase in the effort on three-dimensional mapping, and analysis of existing microstructure data. (Gregg [Larson]; A.M. Pederson and T. Shea, Applied Physics Laboratory)

#### *Eastern Boundary Current Systems*

The overall goal is to understand flow mechanisms in Eastern

Boundary Current systems, in particular the California Current system, on scales of 100 to 1,000 km. Collaborative studies to investigate seasonal (and higher frequency) fluctuations in the California Undercurrent off Oregon, the cross-structure of the undercurrent, and its relationship to the poleward undercurrent that occurs over the shelf have been carried out. Five current meter moorings were deployed along a line off Oregon in 100 m, 300 m, 600 m, 1100 m, and 2500 m of water from October 1977 through October 1978. Hydrographic surveys to 126°00'W were made at approximately six-week intervals. Analyses of the data are nearing completion. (Hickey, Beck, Geier, Ripley; J. Huyer and R. L. Smith, Oregon State University)

It is now proposed to investigate the interannual variability of the seasonally-averaged data discussed by Hickey (1979), as well as possible mechanisms for the large-scale countercurrents that are observed along the coast. Driving mechanisms for the poleward undercurrent will be investigated using historical hydrographic and CTD data from the whole west coast. (Hickey [Pola])

#### *Statistical Theoretical Methods in Ocean Dynamics*

The generation of mesoscale eddies by uniform flow across topography (a component of a U.S./U.S.S.R. POLYMODE investigation) is being examined. One of the possible mechanisms for the generation and maintenance of oceanic mesoscale eddies is the interaction of large-scale flow with mesoscale topographic features. Including latitudinal variation of Coriolis parameter (Beta-effect), flow from the west is an efficient source of eddy energy while flow from the east is ineffective. Indeed, if a model flow is

linearized in the eddy-eddy interactions, the topography appears as too effective at inhibiting flow from the west. Thus the role of eddy interactions, together with a mechanism for dissipation of eddy energy, is essential to establish a statistically stationary eddy energy density and stationary rate of energy extraction from mean flow. There are indications that eddy interactions become important in three ways: (1) there is a tendency to develop a correlation between vorticity and topography reduced energy transfer from the mean flow, (2) the presence of a vigorous eddy field reduces dependence on the sense of mean flow from west or east, and (3) the tendency for topographic interaction with mean zonal currents to produce meridional eddy currents is reduced.

A theory has been developed to predict the role of irregular bathymetry in the dynamics of the Antarctic Circumpolar Current. (Holloway)

Numerical simulations of turbulent mixing of a passive scalar contaminant will be compared with predictions of a statistical closure theory. Investigations will be carried out for two- and three-dimensional flows over a range of Prandtl numbers. The immediate goal is to predict spectra of scalar variance, both to examine power law subrange proposals and to compute time evolution of spectra at moderate Reynolds and Peclet numbers. Extensions of this work to predict anisotropic mixing in large scale quasistrophic motion and in smaller scale inertial-buoyant motion, including spatial transport of scalar concentration, will be considered.

Programs for high resolution computer simulation of a passive scalar contaminant stirred in a two-dimensional flow field are being developed. Discussions with col-

leagues have begun to clarify the relevance of this research to large-scale chemical stirring and mixing in the oceans. (Holloway [Kristmannsson])

Investigations have shown that the oceanic internal wave field is too energetic to be treated as an assemblage of weakly interacting waves. Recent discussions of results of weak wave theory should be questioned more critically. Possible progress by renormalization of wave interaction equations is considered. (Holloway)

A new project -- statistical dynamics of ocean eddies, circulation, and mixing -- is being undertaken. (Holloway, Dworski, [Kristmannsson])

#### *Internal Wave Studies*

Nonlinear features of internal waves on the continental shelf were deduced from the application of satellite data to the evaluation of parameters in cnoidal wave theory. A program centered on the generation and propagation of very large amplitude internal waves has been initiated. (Apel [H. Miller]; J. Holbrook, Pacific Marine Environmental Laboratory)

#### *Hydrodynamics of Amplitude-Modulated Water Waves*

Self-modulation of deep-water gravity waves is known to occur; this is because of an inherent instability of these waves. Ultimately, the instability leads to the formation of wave packets. In shoaler waters, gravity waves are more stable; yet mathematical solutions exist that describe modulated waves. In this study, we will mechanically force modulated wave trains and compare the resulting wave development with the theoretical calculations. (L.H. Larsen)

### *Mid-Ocean Acoustic Transmission Experiment*

MATE acoustic data processing has entered a new phase of constrained path examination. Recalling the hypothesis that we model each pulse as consisting of a small number of arrivals from various ray paths (in the geometrical sense), each arrival being individually scaled and time shifted versions of what would arrive in a single path ideal environment, we write the arrived model signal

$$s(t) = \sum_{i=1}^N a_i r(t - \tau_i)$$

where  $N$  is the number of paths,  $r$  the expected arrival in an ideal single path case (deemed the replica). Our technique solves for the amplitudes,  $a_i$ , and time shifts,  $\tau_i$ , in an optimum way. The constrained path processing fixes the first arrival,  $i = 1$ , to within a period of the previous arrival of that frequency (continuous phase) and allows the second arrival,  $i = 2$ , to adjust for the best possible answer. The number of paths,  $N$ , is set to 2. This allows much more rapid processing; the goal is to obtain a fine series of amplitudes and arrival times for the first arrival uncontaminated by later arrivals. Since 1 February, 9600 pulses at two receivers have been processed (42 hours realtime).

The data set that has been processed supports the results obtained at Cobb in 1971, extending the results to 2 and 13 kHz and ensures the removal of any multipath contamination. The acoustic data will be an integral part of a thesis to be completed this year. This work will contain, in addition to the acoustic series, an environmental spatial series, obtained with SPURV simultaneously with the pulse propagat-

ing, which will focus on determining the features important to sound propagation. (Ewart [Reynolds])

### *Effect of Continental Shelves on Tides*

One of the most important factors influencing coastal tides is the character of the adjacent continental shelf. A continental margin boundary layer theory has been derived and is used to discuss several different aspects of the effect of continental shelves on tides. The main results are as follows:

- 1) The theory suggests, in accordance with observations, that semidiurnal, but not diurnal, tides should be amplified on wide shelves in mid and low latitudes.
- 2) Continental shelf tidal resonance occurs when the shelf scale ( $\alpha$  = shelf bottom slope,  $\omega$  = tidal frequency) is approximately equal to the shelf width. Theoretical arguments and observations can be used to show that shelf resonance occurs (for example, along sections of the northwest Australian shelf).
- 3) Given the easily obtained coastal tide, theory shows that tides over the continental shelf and slope can be approximately estimated analytically. Calculations using simple prediction formulae can be done on a hand calculator. Subject to some restrictions, a very simple and inexpensive method is thus available for estimating barotropic tides on continental shelves.

- 4) An appropriate boundary condition for global numerical tidal models, which cannot resolve the continental margin region, can be derived. For diurnal tides, this boundary condition can be well approximated by an impermeable wall condition at the deep-sea continental slope boundary. For the semidiurnal tides, the impermeable wall condition usually, but not always, suffices; it can break down on very wide continental shelves. (Clarke [Battisti])

#### *Nonlinear Generation of Long-Period Tides on Continental Shelves*

Observations indicate that fortnightly and monthly tides frequently have coastal amplitudes 10 to 100 times larger than the corresponding equilibrium tide. The largest discrepancies generally occur for the fortnightly  $MS_f$  tide which tends to be most strongly amplified on shelves where the  $M_2$  and  $S_2$  tides are larger. Since the tidal frequencies are such that  $(MS_f) = (S_2) - (M_2)$ , the enormously increased tide may be due to the nonlinear interaction of the  $M_2$  and  $S_2$  tides. Preliminary analysis suggests that generation is mainly due to the nonlinear coupling of the  $M_2$  and  $S_2$  tidal currents associated with bottom friction. Consequently, the equations of motion for the long-period tides turn out to be exactly the same as those for the theory of wind-driven motion except that the bottom stress replaces the wind stress. In view of this, it is proposed that the simple successful forced long-wave theory for wind-driven motion on continental shelves be used to analyze and understand long-period tidal generation. It is anticipated that the proposed study will also, because of the

simple time harmonic dependence of the driving force, yield further insight into the dynamics of low-frequency motions on shelves in general. (Clarke [Battisti])

#### *Transport of Dissolved and Suspended Matter in the Washington-Oregon Coastal Zone*

The goal of this research is to provide tested predictive models to characterize the velocity field and the associated movement of suspended matter in coastal areas of the Pacific Northwest. We are focusing on the following model, laboratory, and field investigations:

- 1) modification of the Hamilton and Rattray (1978) circulation model to allow better resolution of vertical mixing processes and to include the poleward undercurrent--a prominent feature on the continental shelf during spring and summer,
- 2) development of a model for the nonlinear interactions between wind-driven currents and tidal currents in the bottom boundary layer,
- 3) testing and improvement of our sediment transport model,
- 4) examination of the mechanisms of momentum transfer in hydrodynamically transitional and rough flows,
- 5) laboratory experiments to determine the influence of mucal binding on the transport of sediment,
- 6) field experiments to determine the role of submarine canyons (Astoria and Quinault) in (a) exchange

of water between the shelf and slope, (b) transport of sediment from coastal areas to the deep sea, (c) causing perturbations of the velocity field over the continental shelf,

- 7) field investigations of nonlocal effects on coastal processes in the Pacific Northwest. (Hickey, J. D. Smith, Nowell, Beck, Geier, Ripley [Bock, Long, Werner])

#### *Transport of Particulate Suspended Matter through Submarine Canyons*

As part of a multiinstitutional research program on sediment transport through submarine canyons, current and CTD measurements will be carried out in Quinault Canyon on the Washington continental slope. In the first year, five bottom-moored current meter arrays will be deployed. In addition to current speed and direction, temperature and conductivity will be recorded. The latter data are needed to differentiate between down-canyon advection and local suspension of sediment. Investigators from Lehigh University will provide transmissometers to be used with some of the current meters. In addition, a CTD/transmissometer grid will be taken around the moorings after deployment in September and another before recovery of the arrays in January. (Hickey, Beck, Geier, Ripley)

#### *Mixing in Highly Stratified Estuaries*

Our recent investigations of mixing in highly stratified estuaries have shown that internal hydraulic processes, including the production and dissipation of nonlinear internal waves, are of critical importance. Our efforts have

focused on the mixing mechanisms in the Duwamish River, a nearby salt-wedge estuary, and in fjords which have a high tidal range. The latter study is being carried out in Knight Inlet, British Columbia.

During the past year, we have concentrated on analyses of the large volume of velocity and density data collected during previous years. In addition, a laterally-averaged, inviscid model of stratified flow has been developed to aid in determining the conditions under which internal waves may grow to unstable amplitudes. A short cruise to the Duwamish River in May 1980, was conducted to obtain echo-sounder images of the pycnocline to compare with the model.

Further data on the development of hydraulic features at the sill of Knight Inlet were obtained during July 1979. Analysis of these data continues to yield details of how the wave energy from the hydraulic phenomena at the sill is redistributed by nonlinear internal waves into the inlet. The waves mix the water column and create a high velocity jet at the base of the pycnocline as they propagate up inlet. These two effects are equally important in attenuating the waves. (J. D. Smith, Nowell [Gardner])

#### *Turbulent Boundary Layer Studies*

The near-bed flow structure in estuaries is dominated most frequently by time-dependent tidal forcing and by nonuniformity due to large scale bed topography. To elucidate the physics of the strictly time-dependent forcing in a tidal boundary layer, a series of experiments was carried out in which all the relevant fluid mechanical parameters were measured over a topographically uniform region of compacted silt.

Triplets of orthogonally mounted miniature ducted impellors to measure the mean velocity and Reynolds stresses at ten levels and five temperature-conductivity sensors to measure the density structure, mounted on a four-meter high tripod, were deployed for four days. The sampled and filtered records of the current meters yield a Nyquist frequency of 3 Hz, while frequency response of the temperature-conductivity sensors is such that structures with scales of approximately 1m may be resolved. The turbulent microstructure was measured at two levels using airfoil shear probes. All the data, as well as output from three accelerometers and compass, were stored on digital tape by a NOVA 1200 computer aboard ship.

Results from the mean velocity profiles yielded a hydraulically rough boundary with high  $z_0$  values. The roughness was found to be attributable to imbricated shell fragments at the surface. The boundary shear velocity was computed directly from the Reynolds stress -- and also from the slope of the velocity profile. They were in close agreement, provided a suitable averaging period was chosen for the stress computation. Spectra of the kinetic energy and cospectra of the stress were calculated to evaluate the influences of low frequency contributions to these fields. Kinetic energy and stress profiles, when scaled by  $u_*$  and  $z_0$ , showed excellent Reynolds number similarity and close agreement with simple steady state closure models. While some hysteresis was observed in the kinetic energy record, such behavior was totally absent in the stress records. (Nowell, J. D. Smith)

#### *Analysis of Circulation Contributions to Upstream Salt Flux*

It has been common in the recent literature to assign a signifi-

cant, sometimes, dominant, role to the lateral circulation's contribution to the upstream salt flux required to balance the downstream flux from the net river outflow. From analysis of variance techniques, we have demonstrated that this result can be obtained artificially from the commonly used method for describing lateral and vertical variations and therefore may not be a proper reflection of the true processes responsible for the salt balance. The difficulty with the fractional-depth method, often used to express the vertical variation of properties, is that it does not make the gravitational potential a unique function of vertical position and thus throws vertical variations, governed by geopotential, into the lateral coordinate. Data from Southampton water were used to demonstrate the above arguments by showing that the actual upstream salt flux results totally from the vertical circulation rather than approximately equally from the lateral and vertical circulations as previously reported. (Rattray, Dworski)

#### *Computation of Periodic Tidal Motions in Deep Estuaries and Fjords*

A procedure has been developed for computing periodic tidal flow in a deep estuary with irregular shoreline configuration and variable depth. The method provides both computational speed and numerical accuracy in a wide variety of problems of practical interest. Included in the formulation are the effects of surface wind stress, boundary friction, and the earth's rotation. Since the motion in the inlet is assumed to be periodic, dependent variables are Fourier decomposed. Nonlinear terms describing advection and friction can be evaluated by an iterative procedure. The time-dependent equations of motion are replaced by an equivalent set of

modal equations; these equations and appropriate boundary conditions can be rephrased in terms of a variational principle. The variational principle is then used together with a finite element method to solve for the unknown variables, i.e., water surface height and depth-averaged velocity throughout the inlet.

To ascertain the potential of the method for resolving efficiently the intricacies of natural tidal flows, we selected a segment of Hood Canal, Washington, and a segment of Knight Inlet, British Columbia. In both cases, finite element grids were prepared manually. For the segment of Hood Canal, the grid consists of 1495 triangles (853 nodes) of gradually varying area. The mesh resolution is finer along the sides of the channel as required for a fair approximation of the bottom topography. The conventional boundary condition at the seaward end of a segment is to prescribe the (periodic) tidal height. However, as we have reported previously, the problem does not seem to be well posed mathematically with that condition. Recently, we have reworked the problem with a different condition which gives much more satisfactory results: specifically, the horizontal current is prescribed across the mouth, and tidal elevation is given at a single station. A comparison of the numerical results with the flow patterns observed in the Department's Puget Sound hydraulic model shows that the scale and location of calculated tidal current flow patterns are very similar to those observed in the model.

The computer model has also been used to calculate the barotropic tides in Knight Inlet, and the results are compared with available field data from experiments conducted jointly by the University of Washington and the Department of the Environment, Canada. Knight Inlet

is a rather strongly stratified fjord throughout much of the year, and a significant portion of the barotropic tidal energy apparently is extracted through certain internal mechanisms associated with the flow over the sills. Notwithstanding this fact, however, the model results agree fairly well with measured tidal flow patterns. In particular, the observed phase difference can be obtained with a linear "frictional" term, regardless of the precise nature of the actual dissipation process. (Winter [Jamart]: C. E. Pearson, Department of Aero-nautics and Astronautics)

## APPLIED OCEANOGRAPHY

*Processes and Resources of the Bering Sea Shelf*

PROBES is a multidisciplinary and multiinstitutional ecosystem study of the Bering Sea focused on the abundant secondary and higher level fauna of outer Bristol Bay. The results of the field studies will form a basis for constructing numerical models of circulation and mixing designed to interface with the overall ecosystems model that is the focal point of PROBES. Physical and biological studies are continuing.

Physical oceanographic studies in outer Bristol Bay: Emphasis is placed on circulation and mixing phenomena associated with well-defined temperature and salinity fronts occurring in the southern Bering Sea. The thrust is to define physical characteristics related to biological patchiness and biological boundaries and to parameterize horizontal mixing and dispersion at scales relevant to observed biological and chemical distributions. Another primary focus is on the response of the surface layer to varying meteorological inputs, e.g., wind, and the consequences for the biological regimes.

Recent results include progress in quantifying the behavior of the surface mixed-layer in response to specific wind events and the response of phytoplankton to the changes. (Coachman, Tripp, Darnall)

Early life history studies of Alaska pollock: The distribution and abundance of larvae, daily larval growth rates, and the larval feeding patterns of the Alaska (walleye) pollock, *Theragra chalcogramma*, in the Bering Sea and

Puget Sound are being determined. (English [Walline])

*Outer Continental Shelf Environmental Assessment Program*

The OCSEAP program is sponsored by NOAA; the objectives are to (1) provide comprehensive environmental and biological data and information on the Alaska outer continental shelf lease area; (2) define the probable ecological impact of oil exploration, production, storage, and shipment on the outer continental shelf; (3) refine the understanding of key ecological dynamic processes; and (4) provide a basis for *a priori* predictive or diagnostic models of the ecosystem response to loading by petroleum and petroleum by-products.

Norton Sound/Chukchi Sea oceanographic processes: Studies of the northern Bering and southern Chukchi seas, including Norton Sound, and of the Bristol Bay area of the southeastern Bering Sea are continuing; in addition, studies of the relationship between these oceanographic regimes are underway. The principal objective is a description and modeling of the circulation of the whole eastern Bering Sea shelf sufficiently detailed to allow predictions of water motion and any associated properties (e.g., pollutants).

The variability of the basic northward transport of water through Bering Strait, based on a seven-month series of current measurements, has been described. The atmospheric mechanism forcing the occasional incidences of southerly transport has been defined.

Under-ice current and pressure measurements in Norton Sound: The primary objective of this work is to ascertain the near-bottom time-varying current and pressure fields in the Norton Sound region during conditions of ice cover. This is necessary to properly model and predict the effect of tides and winter vertical velocity structure in the transport of material, to determine the movement of sediment in winter, and to define the temporal nature of the circulation south of Bering Strait during times when the system is known to undergo major reductions and reversals in flow. This research forms part of an ongoing effort to understand the physical oceanography of the northern Bering Strait region.

A total of 15 moorings were installed in October-November 1979 and were recovered during the summer of 1980. (Aagaard, Tripp)

Bristol Bay oceanographic processes: Studies to improve our understanding of the hydrography, circulation, and dominant mechanisms driving the shelf sea regime of the southeastern Bering Sea are continuing. Specific attention is being directed to meteorological forcing of shelf flows, formation and mixing of finestructure found in the interaction zone between the middle and outer shelf water masses, and formation and significance of the fronts that separate the shelf waters into three distinct oceanographic regimes.

A model of cross-shelf transport of properties based on conservation of salt has been developed and the results used to estimate the fluxes of nonconservative properties (e.g., nutrients). (Coachman, Tripp, Darnall; J. D. Schumacher, Pacific Marine Environmental Laboratory)

Bering/Chukchi seas acoustic studies: Acoustic and net samples to determine the abundance and distribution of zooplankton in the BLM oil lease sites, in the Navarin Basin of the Bering Sea, and in the Chukchi Sea were collected in the spring of 1980, using the icebreaker *Polar Star*. (English, Daly)

#### *Deep Ocean Mining Environmental Study*

The objective of DOMES is to identify potential environmental impact problems to be expected from commercial-scale mining of deep ocean manganese nodules. Baseline studies on existing environmental conditions (Phase I) were completed before studies concerned with prototype mining tests (Phase II) were undertaken.

The mining systems involved in commercial recovery of manganese nodules will recover nodules by means of a collector that will either be towed or self-propelled and will draw them through a pipe to the surface; at the same time, bottom sediment will also be drawn into the collector. Most of this unwanted sediment will be rejected at, or just above, the collector; some entrained sediment, together with nodules and bottom water, will be hydraulically drawn to the mining vessel. The nodules will be separated on the mining vessel, and the residual mixture of bottom water, sediments, nodule fragments, and benthic biota will be discharged at the surface. The assessment of potential impacts resulting from commercial mining operations depends upon the identification and characterization of materials included in this discharge.

The preliminary estimates of the mining discharge characteristics were made from information provided

by the mining consortia prior to mining tests. Two pilot-scale mining tests conducted in 1978 provided the first opportunity to observe mining operations and allowed comparisons of earlier estimates of mining perturbations with actual results. During these tests discharge volume, particulate concentration, and temperature were measured on each mining vessel. Studies to delineate the surface and benthic plumes and to assess biological impacts were conducted during these tests from the NOAA Ship *Oceanographer*. (Burns, Ozturgut)

Dissolved components of discharge: Three dissolved components of the discharge -- nutrient ions, gases, and metals -- were investigated. First, the dilution level at which the dissolved components can be detected in a plume was determined. Then the potential environmental effect of each component was considered and the possibility of detecting the effect was determined.

The presence of discharge nutrient ions in the mixed layer could not be measured beyond a dilution factor of approximately  $3.3 \times 10^{-4}$ . An increase in primary productivity in the immediate vicinity of the mining ship equivalent to the productivity of  $2.7 \text{ km}^2$  of ambient water could be attributable to the nitrate ions in the yearly discharge of a single commercial-scale mining ship. At no age of the discharge plume could this increase be measured.

Supersaturation of air gases in the discharge of the air-lift system would be expected but would be measurable only to dilution factors of approximately  $1 \times 10^{-2}$ . Dilutions of this magnitude occur within minutes after discharge. Consequently, no threat of gas-bubble disease from the supersaturation of gases can be expected.

The concentrations of several metals in the two source waters of the discharge (interstitial and bottom water) are different, but neither would be detected in the surface mixed layer farther than a kilometer from a mining ship. However, no samples for dissolved metals were taken during the monitoring program and, since the experimental evidence for metal release from discharge solids is inconclusive, it is impossible to predict dispersion patterns for dissolved metals from the discharge solids. The discharge at relatively high concentrations did not affect the rate of primary productivity or the uptake of limiting nutrient ions by phytoplankton. However, the possibility of the biomagnification of metals cannot be ruled out until unequivocal data on the release of metals from the discharge solids is in hand. (Ozretich)

Increased oxygen demand and microbial biomass: Detection of the sediment POC and maximized oxygen demand from the initial organic matter adsorbed to the sediment particles would be limited to the upper 50 m of the water column within 15 km of the mining ship. The sediment of the benthic plume would settle to the bottom without providing additional oxidizable carbon to bacteria or higher organisms because the organic carbon on the sediment is essentially refractory. The macerated and smothered bottom fauna would be consumed by other organisms, but the amount of oxygen utilized would be undetectable and trivial compared to the vast oxygen pool of the bottom water.

Sediment particles have been shown to stimulate bacterial growth, and this process may have contributed to elevated ATP concentrations. However, the short time that discharge solids remain in a water parcel precludes a significant alte-

ration of the oxygen concentration in the mixed layer or thermocline. (Ozretich)

Effect of deep-sea mining on marine phytoplankton and primary productivity: The potential effects of the deep-sea mining of manganese nodules on the local phytoplankton photosynthesis and primary production were investigated during the autumn of 1978 in the tropical eastern North Pacific Ocean. Experiments were conducted to study the short-term influence of the mining discharge on marine photosynthesis in terms of light reduction by the discharge particulates and of chemical inhibition by the release of heavy metals from the bottom sediment.

From the experimental results, it is predicted that a significant, short-term reduction in primary production will occur in the plume of mining discharge. Effects due to nutrient-enrichment or heavy metal toxicity are projected to be negligible. Long-term and large-scale changes in phytoplankton species composition or primary production due to the mining operation are not anticipated. (Anderson; A.T.H. Chan, University of British Columbia)

Impact of a pilot-scale manganese nodule mining test on the benthic community : The purpose of this project was to assess the impact on the benthos of a pilot-scale manganese nodule mining operation near DOMES site A in the central Pacific Ocean. However, assessment was ineffectual due to the interaction of natural spatial variability with the noncorrespondence between intended and actual mining locations; thus the power of the statistical tests that could be used to detect mining-associated changes in benthic populations was severely limited. Instead of the planned local compari-

sions of pre-mining and post-mining samples, only broad regional estimates could be made with statistical validity. The limited duration and spatial extent of mining was not anticipated to affect the entire ( $10^3 \text{ km}^2$ ) region of the study, and no significant before-after differences were found on this unrealistically large scale. Power (beta error) curves show that macrofaunal population changes in excess of 50% over the entire region would have been necessary to assure ( $P > 0.95$ ) detection of a before-after difference. Hence, there is no assurance from this sampling program that a substantial mining effect did not indeed occur. (Jumars, Self)

#### *Prediction of Oil Slick Motion in Coastal Waters*

This project is an outgrowth of the tidal current work previously carried out. The ability to predict the motion of oil spilled in near-shore coastal waters is obviously of considerable practical importance. Briefly stated, the movement of oil on water is conventionally described by three spreading modes: inertial (gravity), gravity spreading as affected by viscous forces, and surface tension. In addition, spreading is influenced by evaporation and dissolution. However, the configuration of an oil slick in a near-shore marine environment will depend more heavily on wind stress and tidal advection. In this project, we have used the periodic tidal model in Hood Canal to provide high-resolution tidal current input to an independently developed oil slick prediction model. Although only hypothetical runs have been performed, the results are very encouraging. Two tentative conclusions can be drawn from the work to date: (1) clean-up strategies based on oil "trajectory" models are inadequate for most inlets and estuaries, and (2) certain modifications of pre-

sently available oil slick prediction models would be desirable; for example, more realistic representation of beach or shore deposition processes should be included. (Winter [Werner])

#### *Effects of an Oil Well Blowout on Zooplankton*

A quantitative acoustic method of assessing zooplanktonic and sound-scattering organisms was carried out in conjunction with the NOAA investigation of the effects of the oil well blowout in the Gulf of Mexico. The results showed that quantitative acoustic methods were adequate to document changes in quantity and quality of target organisms that could be related to the effects of oil in the water column. The changes in organisms were closely related to strong oil odors but not to surface oil or distance from the well. (English, Macaulay, Daly)

#### *Collaborative Acoustic Analyses*

This study was designed to improve scientific capability of both the Resource Assessment and Conservation Engineering Division of the National Marine Fisheries Service and the University of Washington through full-time collaboration with Department of Oceanography research specialists who at the same time will gain experience in mission-oriented research on resource assessment methodology. Software support for the hydroacoustic program and a plan for a NOAA effort to assess the Antarctic euphausiid population by acoustic methods and net catches are being carried out. (English, Macaulay)

#### *Suspended Sediment Study*

A field program was conducted in the fall of 1980 at a station in Prudhoe Bay, Alaska, to obtain samples of the sediments in the

water column as a function of time during the fall freeze period. A Rosette sampler with nine sediment traps was deployed. The experiment is designed so that eight traps will be open for successive two-week intervals, and one sediment trap will stay open throughout the 16-week deployment period. (L.H. Larsen, Lorenzen)

#### *Stability of Dredge Materials in Elliott Bay*

The SDS system was deployed in August 1980 at a site in Elliott Bay where dredge materials have been dumped. The purpose of this study is to examine the stability of this deposit to erosion by tidal currents. (L.H. Larsen)

#### *Tribal Fish Ticket Software System*

The present Tribal Fish Ticket software system has been extended by (1) building a new data bank of Game Department Steelhead data, (2) modifying the current retrieval programs to act on this new data, (3) adding one or more new summary catch reports to the present processing program, (4) revising the comparison system of fish ticket numbers, and (5) adding an income summary data from which income analysis histograms can be derived. (Sands, Green, Lee)

## FACULTY AND PROFESSIONAL STAFF

*Administration*

D. James Baker, Jr., Chairman

George C. Anderson, Associate Chairman for Research

Richard W. Sternberg, Associate Chairman for Instruction

*Faculty*

Knut Aagaard, Ph.D., Washington. Research Professor. Physical oceanography, ocean circulation, Arctic oceanography.

Saiyed Ahmed, Ph.D., Frankfurt. Research Associate Professor. Ecosystem regulation, control mechanisms in phytoplankton, fungi, and bacteria.

George C. Anderson, Ph.D., Washington. Professor and Associate Chairman for Research. Biological oceanography, plankton ecology.

Jack W. Anderson, Ph.D., California, Irvine. Affiliate Associate Professor. Biological oceanography, effects of oil pollution in marine environments.

John R. Apel, Ph.D., Johns Hopkins. Affiliate Professor. Waves and instabilities, remote-sensing oceanography.

William I Aron, Ph.D., Washington. Affiliate Professor. Fisheries oceanography, distribution and abundance of fish in relationship to oceanographic conditions.

D. James Baker, Jr., Ph.D., Cornell. Professor and Chairman. Physical oceanography, large-scale ocean circulation, Antarctic oceanography, instrumentation.

Edward T. Baker, Ph.D., Washington. Research Associate (Affiliate). Geological oceanography, distribution and composition of suspended particulate matter.

Karl Banse, Ph.D., Kiel (Germany). Professor. Biological oceanography, plankton production, polychaete systematics.

Clifford A. Barnes, Ph.D., Washington. Professor Emeritus. Physical oceanography, water properties, circulation.

Robert E. Burns, Ph.D., Washington. Affiliate Associate Professor. Environmental assessment, continental shelf, estuaries.

Glenn A. Cannon, Ph.D., Johns Hopkins. Affiliate Associate Professor. Physical oceanography, estuarine and coastal processes.

Roy Carpenter, Ph.D., California, San Diego. Associate Professor. Marine geochemistry of metals and hydrocarbons in coastal zones.

Nikolas I. Christensen, Ph.D., Wisconsin. Adjunct Professor. High-pressure physics, tectonics, structure and constitution of the earth's interior.

Allan Clarke, Ph.D., Cambridge. Research Associate. Physical oceanography, wind-forced lake and shelf water motion, upwelling, tides, climate.

Joel D. Cline, Ph.D., U.C.L.A. Affiliate Assistant Professor. Geochemistry research, nutrient cycles, isotope geochemistry.

Lawrence K. Coachman, Ph.D., Washington. Professor. Physical oceanography, water properties circulation, Arctic oceanography.

Joe S. Creager, Ph.D., Texas A&M. Professor. Sea-level changes, recent marine sediments, shallow-water sediment transportation.

William O. Criminale, Jr., Ph.D., Johns Hopkins. Professor. Geophysical fluid mechanics, air-sea interactions.

- Benoit Cushman-Roisin, Ph.D., Florida State. Research Associate. Physical oceanography, upper ocean dynamics.
- David M. Damkaer, Ph.D., George Washington. Affiliate Assistant Professor. Biological oceanography, ecology and systematics of plankton copepods.
- Eric D'Asaro, Ph.D., M.I.T. Research Associate. Physical oceanography, upper ocean dynamics, internal waves, and mixing processes.
- John R. Delaney, Ph.D., Arizona. Research Assistant Professor. Igneous petrology, properties, and origin of the oceanic crust and upper mantle.
- Alyn C. Duxbury, Ph.D., Texas A&M. Research Associate Professor. Descriptive physical oceanography, mechanics of estuarine and coastal circulation.
- Brady Elliott, Ph.D., Texas A&M. Research Associate. Physical oceanography and description of mesoscale circulation and dynamics.
- Steven R. Emerson, Ph.D., Columbia. Assistant Professor. Marine geochemistry, sediment diagenesis.
- T. Saunders English, Ph.D., Washington. Associate Professor. Biological oceanography, nekton, sampling problems, Arctic plankton ecology.
- Terry E. Ewart, Ph.D., Washington. Research Professor. Physics, ocean microstructure, diffusion, acoustic transmission.
- Richard A. Feely, Ph.D., Texas A&M. Research Associate (Affiliate). Chemical oceanography, marine geochemistry and sedimentation processes.
- Richard H. Fleming, Ph.D., California, Berkeley. Professor Emeritus. Physical and general oceanography.
- Bruce W. Frost, Ph.D., California, San Diego. Professor. Biological oceanography, marine zoogeography, plankton ecology and systematics.
- Jerry A. Galt, Ph.D., Washington. Affiliate Assistant Professor. Physical oceanography, numerical modeling and general circulation.
- Jan Garmany, Ph.D., California, San Diego. Research Assistant Professor. Geophysics, theoretical seismology.
- Michael C. Gregg, Ph.D., California, San Diego. Research Professor. Physical oceanography, ocean microstructure.
- David Halpern, Ph.D., M.I.T. Affiliate Associate Professor. Physical oceanography, ocean-atmosphere response studies.
- Stanley P. Hayes, Ph.D., Cornell. Senior Research Associate (Affiliate). Physical oceanography, air-sea interaction, internal waves.
- John I. Hedges, Ph.D., Texas. Assistant Professor. Organic geochemistry, characterizing marine-derived organic molecules in coastal zones.
- Dora P. Henry, Ph.D., California, Berkeley. Research Professor. Systematics and ecology of barnacles.
- Barbara Hickey, Ph.D., California, San Diego. Research Associate Professor. Physical oceanography, the dynamics of circulation in the equatorial region and on the continental shelf.
- Gregory Holloway, Ph.D., California, San Diego. Research Assistant Professor. Physical oceanography, turbulence theory, geophysical fluid dynamics.
- Mark L. Holmes, Ph.D., Washington. Research Associate (Affiliate). Geological oceanography, marine geophysics, continental margins.
- Donald W. Hood, Ph.D., Texas A&M. Senior Research Associate. Chemical oceanography, carbon budgets and exchanges.
- H. Paul Johnson, Ph.D., Washington. Research Associate Professor. Paleomagnetism and marine geophysics.
- Peter A. Jumars, Ph.D., California, San Diego. Associate Professor. Biological oceanography, benthos.
- Michael R. Landry, Ph.D., Washington. Research Assistant Professor. Biological oceanography, zooplankton-phytoplankton interactions, grazing, predation.

- Lawrence H. Larsen, Ph.D., Johns Hopkins. Research Associate Professor. Physical oceanography, hydrodynamics, waves.
- Joyce C. Lewin, Ph.D., Yale. Research Professor. Physiology and systematics of diatoms, biological deposition of silica.
- Brian T.R. Lewis, Ph.D., Wisconsin. Associate Professor. Marine geophysics, marine seismology.
- Clive R.B. Lister, Ph.D., Cambridge. Professor. Geothermal studies, marine geophysics, global tectonics.
- Cho-Teng Liu, Ph.D., Washington. Research Associate. Physical oceanography, equatorial ocean dynamics.
- Carl Lorenzen, Ph.D., Cornell. Research Associate Professor. Biological oceanography, marine food chain dynamics, carbon cycling in the ocean.
- Seelye Martin, Ph.D., Johns Hopkins. Research Professor. Geophysical fluid dynamics, properties of sea-ice.
- Thane H. McCulloh, Ph.D., U.C.L.A. Affiliate Professor. Geology of petroleum, geophysical prospecting, continental shelf and slope resources.
- Dean A. McManus, Ph.D., Kansas. Professor. Geological oceanography, continental shelf sediments.
- Ronald T. Merrill, Ph.D., California, Berkeley. Professor. Geomagnetism and paleomagnetism.
- Harold O. Mofjeld, Ph.D., Washington. Affiliate Assistant Professor. Physical oceanography, theory and observation of tides, large time-dependent motion.
- Stanley R. Murphy, Ph.D., Washington. Professor. Physical oceanography, underwater acoustics, ocean turbulence.
- James W. Murray, Ph.D., M.I.T./Woods Hole Oceanographic Institution. Assistant Professor. Marine geochemistry, trace metals.
- Arthur R. M. Nowell, Ph.D., U.B.C. Research Assistant Professor. Physical oceanography, turbulent boundary layer dynamics, sediment transport.
- Mary Jane Perry, Ph.D., California, San Diego. Research Assistant Professor. Biological oceanography, phytoplankton physiology, nutrient cycling.
- Maurice Rattray, Jr., Ph.D., Caltech. Professor. Physical oceanography, hydrodynamics, estuarine circulation, internal waves.
- Ronual Reichard, Ph.D., New Hampshire. Research Associate. Physical oceanography, estuarine processes, numerical modeling of circulation, turbulence, and transport dynamics.
- Francis A. Richards, Ph.D., Washington. Professor. Chemical oceanography, nutrient and gas cycles in the sea, oxygen-deficient marine environments.
- Stephen C. Riser, Ph.D., Rhode Island. Research Associate. Physical oceanography, large- and meso-scale circulation of the ocean.
- Gunnar I. Roden, M.S., U.C.L.A. Senior Research Associate. Physical oceanography, ocean fronts, mesoscale ocean circulation and structure, time-series analysis.
- Thomas B. Sanford, Ph.D., M.I.T. Research Professor. Physical oceanography, measurements and interpretation of motionally-induced electric and magnetic fields in the deep sea and within channels.
- William R. Schell, Ph.D., Washington. Adjunct Associate Professor. Biogeochemistry, radionuclide tracer methods, sedimentation rates, trace metals.
- Amy Schoener, Ph.D., Harvard. Research Assistant Professor. Biological oceanography, artificial substrate colonization, biogeography, benthos.
- J. Dungan Smith, Ph.D., Chicago. Professor and Chairman, Geophysics Program. Coastal and estuarine physical oceanography, turbulent boundary layer mechanics, sediment transport processes.

Richard W. Sternberg, Ph.D., Washington. Professor and Associate Chairman for Instruction. Geological oceanography, marine sedimentation processes.  
Richard J. Stewart, Ph.D., Stanford. Adjunct Associate Professor. Geological oceanography, sedimentary petrology, sediment diagenesis.  
Minze Stuiver, Ph.D., Groningen (Netherlands). Adjunct Professor. Chemical oceanography, limnology, isotope geology, geochronometry.  
Bruce A. Taft, Ph.D., California, San Diego. Research Associate Professor. Physical oceanography, ocean circulation.  
Pierre L.R. Welander, Ph.D., Stockholm. Professor. Theory of general ocean circulation, large-scale atmosphere-ocean interaction.  
Donald F. Winter, Ph.D., Harvard. Professor. Applied mathematics, hydrodynamics, biological modeling.  
Warren S. Wooster, Ph.D., California, San Diego. Adjunct Professor. Physical oceanography, ocean circulation, fishery oceanography and ocean affairs.

*Professional Staff*

Laurie Balistrieri  
Robert Barrick  
John R. Beck  
Beatrice Booth  
Kendra Daly  
Clark Darnall  
Earl Davis, Ph.D.  
Quay Dortch, Ph.D.  
J. George Dworski  
Andrew Hafferty  
Michael L. Healy, Ph.D.  
Gayle Heron  
Rita Horner, Ph.D.  
Rex Johnson  
Peter Kauffman  
Dale Kisker

Kathy Krogslund  
Mary C. Larsen  
Joyce Lehner-Fournier  
Noel B. McGary  
Michael Peterson  
Willis K. Peterson  
James Postel  
Barbara Quay  
Dave Roetcisoender  
Edward Roy  
Walter Sands  
Robert L. Self  
Leanne Stahl  
Dave Thoreson  
Richard B. Tripp  
Karen Zakar

## DOCTOR OF PHILOSOPHY DEGREES AWARDED IN 1979-80 WITH TITLES OF DISSERTATIONS

Joseph T. Bennett: "The biogeochemical significance of zooplankton fecal material in a biological productive, temperate fjord."

Jerre E. Bradt: "Initial value problems in stratified shear flows."

John P. Christensen: "Oxygen consumption, denitrification, and sulfate reduction rates in coastal marine sediments."

Raymond E. Cranston: "Chromium species in natural waters."

Frances Quay Dortch: "Nitrate and ammonium uptake and assimilation in three marine diatoms."

Steven O. Howe: "Biological consequences of environmental changes related to coastal upwelling: a simulation study."

Bruno Jamart: "Finite element computation of barotropic tidal motion in deep estuaries."

Edward G. Josberger: "Laminar and turbulent boundary layers adjacent to melting vertical ice walls in salt water."

Nancy B. Kachel: "A time-dependent model of sediment transport and strata formation on a continental shelf."

Stephen A. Lieberman: "Stability of copper complexes with seawater humic substances."

Cho-Teng Liu: "An energy-balance climate model with separate land and oceanic effects."

Charles E. Long: "A simple model for time-dependent, stably stratified, turbulent boundary layers."

Carl A. Paul: "The structure and variability of the Atlantic North Equatorial Countercurrent during GATE: August-September 1974."

Clarence G. Pautzke: "Phytoplankton primary production below Arctic Ocean pack ice: and ecosystems analysis."

Robin M. Ross: "Carbon and nitrogen budgets over the life of Euphausia pacifica."

George F. Spooner: "Fluctuations in geophysical boundary layers."

James H. Swift: "Seasonal processes in the Iceland Sea, with especial reference to the relationship to the Denmark Strait overflow."

## MASTER OF SCIENCE DEGREES AWARDED IN 1979-80

James A. Carton  
 Howard P. Freitag  
 Eugene D. Gallagher  
 Janice L. Garver  
 Thomas F. Gross  
 Susan E. Hamilton  
 Christine N. Hanley  
 Connie Powell Haury  
 Janice L. Johnson  
 Carolyn J. Jones

Jill L. Karsten  
 Charles N. Katz  
 Nordeen G. Larson  
 Eric L. Lindstrom  
 Rene Pinet-Plasencia  
 Edward H. Roy  
 Steve R. Walter  
 Bettie B. Ward  
 Nicholas A. Welschmeyer

## BACHELOR'S DEGREES AWARDED IN 1979-80

Kenneth F. Abasolo  
 Brian S. Anderson  
 Stuart B. Archer  
 Mary C. Baker  
 Robert W. Baker  
 Kirk D. Baldwin  
 Emabid E. Bechara-Rolando  
 Mary C. Benson  
 Andrea G. Boughner  
 Arland D. Buchanan  
 Marcia L. Campbell  
 Sean W. Chamberlin  
 Timothy J. Clement  
 Peter J. Davidson  
 Thomas A. Demshki  
 Jon B. Eggers  
 Harald R. Ehlers  
 Alan Fudge  
 Eunibis M. Gomez  
 Scott G. Grieb  
 Moochi Han  
 Verle Heyer  
 Kathryn L. Hjortedal  
 Frank S. Holman  
 Onwukwe E. Ibeabuchi  
 Eric J. Jaeger  
 Eric S. Johnson  
 James K. King  
 James K. Klinck  
 Michael R. Krier

Gunnar G. Lauenstein  
 Coleman L. Lawrence  
 William R. Martin  
 James L. Mead  
 Douglas A. Milward  
 David J. Murphy  
 Jeffrey M. Napp  
 Kathleen K. Newell  
 Jimmy R. Page  
 Peter E. Pine  
 Russel N. Price  
 Lewis C. Rabb  
 Brian E. Reid  
 Kevin K. Roe  
 Sigrid A. Salo  
 Richard D. Schnatterly  
 Kristian K. Schonberg  
 Diane V. Shaw  
 David K. Shroyer  
 Dwight D. Trueblood  
 Thomas J. Valentine  
 Timothy M. Vogel  
 William E. Weigand  
 Joseph M. Weikel  
 Angela A. Westman  
 Randall E. Whitten  
 Leland A. Wight  
 James R. Wilhite  
 Brian J. Williams  
 Timothy B. Wright

## CONTRIBUTIONS

Aagaard, K. (in press) Deep circulation in the Arctic Ocean. *Deep-Sea Research.*

No. 1168

Anderson, J.J. (1979) Nutrient chemistry in the tropical North Pacific DOMES sites A, B, and C. In Bischoff, J.L. and D.Z. Piper (eds.), *Marine Geology and Oceanography of the Central Pacific Manganese Nodule Province*: 113-161. Plenum Publishing Corporation.

No. 1056

Baker, E.T., R.A. Feely, and K. Takahashi (1979) Chemical composition, size distribution, and particle morphology of suspended particulate matter at DOMES sites A, B, and C: Relationships with local sediment composition. In Bischoff, J.L. and D.Z. Piper (eds.), *Marine Geology and Oceanography of the Central Pacific Manganese Nodule Province*: 163-201. Plenum Publishing Corporation.

No. 1052

Balistrieri, L., P.G. Brewer, and J.W. Murray (in press). Scavenging residence times of trace metals and surface chemistry of sinking particles in the deep ocean. *Deep-Sea Research.*

No. 1182

Banse, K. (1979) Ampharetidae (Polychaeta) from British Columbia and Washington. *Canadian Journal of Zoology* 57: 1543-1552.

No. 1070

Banse, K. (1979) Sabellidae (Polychaeta) principally from the northeast Pacific Ocean. *Journal of the Fisheries Research Board of Canada* 36: 869-882.

No. 1081

Banse, K. (1980) Terebellidae (Polychaeta) from the northeast Pacific Ocean. *Canadian Journal of Fishery and Aquatic Sciences* 37: 20-40.

No. 1106

Banse, K. (1980) Microzooplankton interference with ATP estimates of plankton biomass - a note. *Journal of Plankton Research* 2: 235-238.

No. 1154.

Banse, K. (in press) Experimental marine ecosystems enclosures in a historical perspective. *Proceedings of the Symposium of Enclosed Marine Ecosystems.*

No. 1174

Banse, K. and S. Mosher (1980) Adult body mass and annual production biomass relationship of field populations. *Ecological Monographs* 50: 355-379.

No. 1142

Barnard, W.D. (1978) The Washington continental slope: Quaternary tectonics and sedimentation. *Marine Geology* 27: 79-114.

No. 1077

Barrick, R.C., J.I. Hedges, and M.L. Peterson (1980) Hydrocarbon geochemistry of the Puget Sound region. I. Sedimentary acyclic hydrocarbons. *Geochemica et Cosmochimica Acta* 44: 1349-1362.

No. 1159

Barton, C.E., R.T. Merrill and M. Barbetti (1979) Intensity of the earth's magnetic field over the last 10,000 years. *Physics of the Earth and Planetary Interiors* 20: 96-110.

No. 1110

Bates, T.S. and R. Carpenter (1979) Determination of organo-sulfur compounds extracted from marine sediments. *Analytical Chemistry* 51: 551-554.

No. 1059

Bates, T.S. and R. Carpenter (1979) Organo-sulfur compounds in sediments of the Puget Sound Basin. *Geochimica et Cosmochimica Acta* 43: 1209-1221.

No. 1084

Bennett, J.T. and R. Carpenter (1979) Concentrations and temporal variations of  $^{210}\text{Po}$ ,  $^{210}\text{Pb}$ , and Al in the surf-zone ecosystem of Copalis Beach, Washington. *Estuarine and Coastal Marine Science* 8: 127-140.

No. 1020

Booth, B. and P.J. Harrison (1979) Effect of silicate limitation on valve morphology in *Thalassina* and *Coscinodiscus* (Bacillariophyceae). *Journal of Phycology* 15: 326-329.

No. 1051

Booth, B.C., J. Lewin, and R.E. Norris (1980) Siliceous nanoplankton. I. Newly discovered cysts from the Gulf of Alaska. *Marine Biology* 58: 205-209.

No. 1149

Bothner, M.J., R.A. Jahnke, M.L. Peterson and R. Carpenter (1980) Rate of mercury loss from contaminated estuarine sediments. *Geochimica et Cosmochimica Acta* 44: 273-285.

No. 1097

Chan, A. (1980) Comparative physiological study of marine diatoms and dinoflagellates in relation to irradiance in cell size. II. Relationship between photosynthesis, growth, and carbon/chlorophyll a ratio. *Journal of Phycology* 16: 428-432.

No. 1145

Chester, A.J. (1978) Microzooplankton relative to subsurface chlorophyll maximum layer. *Marine Science Communication* 4: 275-292.

No. 1047

Christensen, J.P. and D.H. Devol (1980) Adenosene triphosphate and adenylate energy change in marine sediments. *Marine Biology* 56: 175-182.

No. 1135

- Christensen, J.P., T.G. Owens, A.H. Devol and T.T. Packard (1980) Respiration and physiological state in marine bacteria. *Marine Biology* 55: 267-276.  
No. 1104
- Christensen, J.P. and T.T. Packard (1979) Respiratory electron transport activity in phytoplankton and bacteria: comparison of methods. *Limnology and Oceanography* 24: 576-583.  
No. 1037
- Clarke, A.J. (1979) On the generation of the seasonal coastal upwelling in the Gulf of Guinea. *Journal of Geophysical Research* 84: 3743-3751.  
No. 1079
- Codispoti, L.A., R.C. Dugdale, and H.J. Minas (in press) A comparison of the nutrient regimes off northwest Africa, Peru, and Baja California. *Rapports et Proces-Verbaux. Conseil International pour l'Exploration de la Mer.*  
No. 1036
- Copping, A.E. and C.J. Lorenzen (1980) Carbon budget of a marine phytoplankton-herbivore system using carbon-14 as a tracer. *Limnology and Oceanography* 25: 873-882.  
No. 1146
- Cranston, R.E. and J.W. Murray (1980) Chromium species in the Columbia River and estuary. *Limnology and Oceanography* 25: 1104-1112.  
No. 1175
- Criminale, W.O. (1980) Effects of mean current and shear on stability of depth distributions of marine phytoplankton. *Journal of Mathematical Biology* 10: 33-51.  
No. 1136
- Damkaer, C.C. and D.M. Damkaer (1979) Henrik Krøyer's publications on pelagic marine Copepoda (1838-1849). *Transactions of the American Philosophical Society* 69, Part 6. 48 pp.  
No. 1030
- Damkaer, D., D.B. Dey, and G.A. Heron (in press) Dose/dose-rate responses of shrimp larvae to UV-B radiation. *Oecologia*.  
No. 1183
- Damkaer, D.M., D.B. Dey, G.A. Heron, E.F. Prentice (1980) Effects of UV-B radiation on near-surface zooplankton of Puget Sound. *Oecologia* 44: 149-158.  
No. 1107
- Damkaer, D. and T. Miozck-Dahl (1980) The plankton expedition and the copepod studies of Friederick and Maria Dahl. In Sears, M. and D. Merriman (eds.), *The Past*: 562-473. Springer Verlag, New York.  
No. 1144

- Dietrich, W.E., J.D. Smith, and T. Dunne (1979) Flow and sediment transport in a sand bedded meander. *Journal of Geology* 81: 305-315.  
No. 1062
- Dortch, Q., S.I. Ahmed and T.T. Packard (1979) Nitrate reductase and glutamate dehydrogenase activities in *Skeletonema costatum* as measures of nitrogen assimilation rates. *Journal of Plankton Research* 1: 169-186.  
No. 1095
- Duxbury, A.C. (1979) Upwelling and estuary flushing. *Limnology and Oceanography* 24: 627-633.  
No. 1014
- Ebbesmeyer, C.C. and C.A. Barnes (1980) Control of a fjord basin's dynamics by tidal mixing in embracing sill zones. *Estuarine and Coastal Marine Science* 11: 311-330.  
No. 1093
- Ebbesmeyer, C.C. and B.A. Taft (1979) Variability of potential energy, dynamic height and salinity in the main pycnocline of the western North Atlantic. *Journal of Physical Oceanography* 9: 1073-1089.  
No. 1080
- Eckman, J.W. (1979) Small-scale patterns and processes in a soft-substrate, intertidal community. *Journal of Marine Research* 37: 437-457.  
No. 1083
- Emerson, S. and M. Bender (in press) Carbon fluxes at the sediment water interface of the deep sea: calcium carbonate preservation. *Journal of Marine Research*.  
No. 1172
- Emerson, S., R.E. Cranston, and P.S. Liss (1979) Redox species in a reducing fjord: equilibrium and kinetic considerations. *Deep-Sea Research* 26: 859-875.  
No. 1099
- Emerson, S., R. Jahnke, M. Bender, P. Froelich, G. Klinkhammer, C Bowser, and G. Setlock (1980) Early diagenesis in sediments from the eastern equatorial Pacific. I. Pore water nutrient and carbonate results. *Earth and Planetary Science Letters* 49: 57-80.  
No. 1160
- Ewart, T.E. (1980) A numerical simulation of the effects of oceanic finestructure on acoustic transmission. *The Journal of the Acoustic Society of America* 67: 496-503.  
No. 1087
- Farmer, D.M. and J.D. Smith (1979) Internal waves during GATE. *Deep-Sea Research* 26: 347-350.  
No. 1043

Farmer, D.M. and J.D. Smith (1980) Tidal interaction of stratified flow with a sill in Knight Inlet. *Deep-Sea Research* 27: 239-254.

No. 1085

Feely, R.A., E.T. Baker, J.D. Schumacher, G.J. Massoth, and W.M. Landing (1979) Processes affecting the distribution and transport of suspended matter in the northeast Gulf of Alaska. *Deep-Sea Research* 26: 445-464.

No. 1040

Feely, R.A., G.J. Massoth and W.M. Landing (in press) Major and trace elements composition of suspended matter in the northeast Gulf of Alaska. *Marine Chemistry*.

No. 1092

Feller, R.J. (1980) Quantitative cohort analyses of a sand-dwelling meiobenthic harpacticoid copepod. *Estuarine and Coastal Marine Science* 11: 459-476.

No. 1122

Feller, R.J. (1980) Development of the sand dwelling meiobenthic harpacticoid copepod *Huntemannia jadensis* Poppe in the laboratory. *Journal of Experimental Biology and Ecology* 46: 1-15.

No. 1148

Feller, R.J., G.L. Taghon, E.D. Gallagher, G.E. Kenny and P.A. Jumars (1979) Immunological methods for food web analysis in a soft-bottom benthic community. *Marine Biology* 54: 61-74.

No. 1082

Friederich, G.E. and L.A. Codispoti (1979) On some factors influencing dissolved silicon distribution over the northwest African shelf. *Journal of Marine Research* 37: 337-353.

No. 1055

Frost, B.W. (1980) The inadequacy of body size as an indicator of niches in the zooplankton. In Kerfoot, C. (ed.), *Evolution and Ecology of Zooplankton Populations*: 742-753. Special Symposia 3. American Society of Limnology and Oceanography.

No. 1063

Frost, B.W. and L.E. McCrone (1979) Vertical distribution, diel vertical migration, and abundance of some mesopelagic fishes in the eastern subarctic Pacific Ocean in summer. *Fishery Bulletin* 76: 751-770.

No. 1039

Garfield, P.C., T.T. Packard and L.A. Codispoti (1979) Particulate protein in the Peru upwelling system. *Deep-Sea Research* 26: 623-639.

No. 1041

Garver, J.L. and J. Lewin (1981) Persistent blooms of surf diatoms along the Pacific coast, U.S.A. I. Physical characteristics of the coastal region in relation to the distribution and abundance of the species. *Estuarine and Coastal Marine Science* 12: 217-229.

No. 1153

- Gregg, M.C. (in press) Zero crossings of temperature microstructure. In Nihoul, J. (ed.), *Marine Turbulence*. Proceedings of the 11th International Liege Colloquium on Ocean Hydraulics May 1979. Elsevier Scientific Publishing Co., New York.
- No. 1102
- Gregg, M.C. (1980) Microstructure patches in the thermocline. *Journal of Physical Oceanography* 10: 915-943.
- No. 1137
- Gregg, M.C. (1980) The three-dimensional mapping of a small thermohaline intrusion. *Journal of Physical Oceanography* 10: 1468-1492.
- No. 1166
- Gregg, M.C. and M.G. Briscoe (1979) Internal waves, finestructure, microstructure and mixing in the ocean. *Reviews of Geophysics and Space Physics* 17: 1524-1548.
- No. 1078
- Gregg, M.C. and J.H. McKenzie (1979) Thermohaline intrusions lie across isopycnals. *Nature* (London) 280: 310-311.
- No. 1086
- Gregg, M.C. and T.B. Meagher (1980) The dynamic response of glass-rod thermistors. *Journal of Geophysical Research* 85: 2779-2786.
- No. 1125
- Gregg, M.C. and A.M. Pederson (1979) High resolution salinity measurements. In Dobson, F., L. Hasse, and R. Davis (eds.), *Instruments and Methods in Air-Sea Interaction*. NATO Publication. Plenum Press, New York.
- No. 987
- Gregg, M.C. and T.B. Sanford (1980) Signatures of mixing from the Bermuda Slope, the Sargasso Sea and the Gulf Stream. *Journal of Physical Oceanography* 10: 105-127.
- No. 1049
- Gross, M.G. and M.L. Healy (1979) Chemical aspect of coastal marine pollution. In Siegel, F. (ed.), *Review of Research of Modern Problems in Geochemistry*: 127-137. Earth Science Series No. 16. UNESCO Publication, Paris.
- No. 1000
- Hanzlick, D.J. and K. Aagaard (1980) Fresh and Atlantic waters in the Kara Sea. *Journal of Geophysical Research* 85: 4937-4942.
- No. 1143
- Hedges, J.I. (in press) Interaction between humic substances and inorganic matter in surface marine sediments. *Méiogeochimie de la Matière Organique à L'interface*.
- No. 1158

Hedges, J.I. and D.C. Mann (1979) The characterization of plant tissues by their lignin oxidation products. *Geochimica et Cosmochimica Acta* 43: 1803-1807.

No. 1100

Hedges, J.I. and D.C. Mann (1979) The lignin geochemistry of marine sediments from the southern Washington coast. *Geochimica et Cosmochimica Acta* 43: 1809-1818.

No. 1101

Heinmiller, R.H., C.C. Ebbesmeyer, B.A. Taft, and O.P. Nikitin (in press) Intercomparisons of POLYMODE XBT and CTD isotherm depths in the north-western Atlantic. *Journal of Physical Oceanography*.

No. 1151

Henshaw, P.C., Jr. and R.T. Merrill (1979) Characteristics of drying remanent magnetization in sediments. *Earth and Planetary Science Letters* 43: 315-320.

No. 1073

Henshaw, P.C., Jr. and R.T. Merrill (1980) Magnetic and chemical changes in marine sediments. *Reviews of Geophysics and Space Physics* 18: 483-504.

No. 1132

Hickey, B.M. (1979) The California current system--hypotheses and facts. *Progress in Oceanography* 8: 191-279.

No. 1038

Hickey, B.M. and P. Hamilton (1980) A spin-up model as a diagnostic tool for interpretation of current and density measurements on the continental shelf of the Pacific Northwest. *Journal of Physical Oceanography* 10: 12-24.

No. 1115

Holloway, G. (1980) Oceanic internal waves are not weak waves. *Journal of Physical Oceanography* 10: 906-914.

No. 1134

Holmes, M.L. and J.S. Creager (in press) Role of the Kaltag and Kobuk faults in the tectonic evolution of the Bering Strait Region. In Hood, D.W. (ed.), *The Eastern Bering Sea Shelf: Oceanography and Resources*.

No. 1152

Hughes, F.W. and M. Rattray, Jr. (1980) Salt flux and mixing in the Columbia River Estuary. *Estuarine and Coastal Marine Science* 10: 479-493.

No. 1089

Irish, J.D., T.E. Ewart, M.D. Levine, and S.A. Reynolds (in press) Simultaneous measurement of the spacial and temporal variability due to internal waves at Cobb Seamount in the North Pacific. *Journal of Geophysical Research*.

No. 1112

Jamart, B.M. and D.F. Winter (1980) Finite element computation of the barotropic tides in Knight Inlet, British Columbia. In Freeland, H.J., D.M.

Farmer and C.D. Levings (eds.), *Fjord Oceanography*: 283-289. Proceedings of the NATO Conference on Fjord Oceanography, Victoria, British Columbia, June 4-8, 1979. Plenum Press, New York.

No. 1155

Jamart, B.M. and D.F. Winter (in press) Finite element solution of the shallow water wave equations in Fournier space, with application to Knight Inlet, British Columbia. In Proceedings of the Third International Conference on Finite Elements in Flow Problems, 10-13 June 1980, Banff, Alberta, Canada.

No. 1118

Jamart, B.M., D.F. Winter, and K. Banse (1979) Sensitivity analysis of a mathematical model of phytoplankton growth and nutrient distribution in the Pacific Ocean off the northwestern U.S. coast. *Journal of Phytoplankton Research* 1: 267-290.

No. 1103

Johnson, H.P. (1979) Magnetization of the oceanic crust. *Review of Geophysics and Space Physics* 17: 215-226.

No. 1058

Josberger, E. (1980) The effect of bubbles released from a melting ice-wall on the melt-driven convection in salt water. *Journal of Physical Oceanography* 10: 474-477.

No. 1088

Keller, B., B.T.R. Lewis, C. Meeder, C. Helsley and R.P. Meyer (1978) Explosion seismology studies of active and passive continental margins. In *Geological and Geophysical Investigations of Continental Margins*: 443-451. The American Association of Petroleum Geologists Memoir No. 29.

No. 1060

Kinder, T.H., J.D. Schumacher, and D.V. Hansen (1980) Observation of a baroclinic eddy: an example of mesoscale variability in the Bering Sea. *Journal of Physical Oceanography* 10: 1228-1245.

No. 1163

King, F.D. and A.H. Devol (1979) Estimates of vertical eddy diffusion through the thermocline from phytoplankton nitrate uptake rates in the mixed layer of the eastern tropical Pacific. *Limnology and Oceanography* 24: 645-651.

No. 1071

King, F.D., A.H. Devol, and T.T. Packard (1978) Plankton metabolic activity in the eastern tropical North Pacific. *Deep-Sea Research* 25: 689-704.

No. 1025

King, K.R. (1979) The life history and vertical distribution of the chaetognath, *Sagitta elegans*, in Dabob Bay, Washington. *Journal of Plankton Research* 1: 153-167.

No. 1072

King, K.R. (in press) Population biology of the larvacean *Oikopleura dioica* in enclosed water columns. Proceedings of the Symposium on Enclosed Marine Ecosystems.

No. 1177

King, K.R., K.T. Hollibaugh, and F. Azam (1980) Predator-prey interactions between the larvacean *Oikopleura dioica* and bacterioplankton in enclosed water columns. *Marine Biology* 56: 49-57.

No. 1117

Lahore, H. (1979) PRIME: the seagoing super-mini computer for you? *Sea Technology* June 1979: 22-24.

No. 1053

Landing, W.M. and R.A. Feely (1981) The chemistry and vertical flux of particles in the northeastern Gulf of Alaska. *Deep-Sea Research* 28: 19-37.

No. 1076

Landry, M.R. (1980) Detection of prey by *Calanus pacificus*: Implications of the first antennae. *Limnology and Oceanography* 25: 545-549.

No. 1131

Larsen, L.H. (1979) Tsunamis hazard along the Washington coast. In *Natural Hazards in Washington's Coastal Zone: An Anthology of Recent Articles*: 38-38. Washington State Department of Emergency Services.

No. 1010

Larsen, L.H. (1979) An instability of packets of short gravity waves in waters of finite depth. *Journal of Physical Oceanography* 9: 1141-1143.

No. 1105

Larsen, L.H. (in press) Modulation solitons and internal waves. In *Proceedings of the Conference on Oceanography from Space. COSPAR/SCOR/IUCRM Symposium*, 26-30 May 1980. Venice, Italy.

No. 1162

Larsen, L.H. (1980) Modulation solitons in inhomogeneous media. *The Physics of Fluids* 23: 2359-2361.

No. 1164

Lewin, J., C.H. Chen, and T. Hruby (1979) Blooms of surf-zone diatoms along the coast of the Olympic Peninsula, Washington. X. Chemical composition of the surf diatom *Chaetoceros armatum* and its major herbivore, the Pacific razor clam (*Siliqua patula*). *Marine Biology* 51: 259-265.

No. 995

Lewin, J., J.R. Colvin and K.L. McDonald (1980) Blooms of surf-zone diatoms along the coast of the Olympic Peninsula, Washington. XII. The clay coat of *Chaetoceros armatum* T. West. *Botanica Marina* 23: 333-341.

No. 1124

Lewin, J., J.E. Eckman, and G.N. Ware (1979) Blooms of surf-zone diatoms along the coast of the Olympic peninsula, Washington. XI. Regeneration of am-

- monium in the surf environment by the Pacific razor clam *Siliqua patula*.  
*Marine Biology* 52: 1-9.
- No. 1048
- Lewis, B.T.R. (in press) Temperatures, heat flow and lithospheric cooling at the mouth of the Gulf of California. *Initial Reports of the Deep Sea Drilling Project*. U.S. Government Office, Washington, D.C.
- No. 1140
- Lewis, B.T.R. (in press) Isostasy, magma chambers, and plate driving forces on the East Pacific Rise. *Journal of Geophysical Research*.
- No. 1176
- Lewis, B.T.R. and W.E. Snydsman (1979) Fine structure of the lower oceanic crust on the Cocos Plate. *Tektonophysics* 55: 87-105.
- No. 1008
- Lindstrom, E.J., D.W. Beringer, B.A. Taft, and C.C. Ebbesmeyer (1980) Absolute geostrophic velocity determination from historical hydrographic data in the western North Atlantic. *Journal of Physical Oceanography* 10: 999-1009.
- No. 1133
- Ling, H.Y. (in press) Radiolaria from the west flank of Leg 49. *Initial Reports of the Deep Sea Drilling Project*. U.S. Government Printing Office, Washington, D.C.
- No. 1022
- Ling, H.Y. and K. Takahashi (in press) Observation on microstructure of selected phaeodarian Radiolaria. *Biq Memoir*. Geological Society of China (Taiwan).
- No. 970
- Lorenzen, C.J. (1979) Ultraviolet radiation and phytoplankton photosynthesis. *Limnology and Oceanography* 24: 1117-1120.
- No. 1091
- Lorenzen, C.J., F.R. Shuman, and J. Bennett (in press) In situ calibration of a sediment trap. *Limnology and Oceanography*.
- No. 1156
- Macaulay, M.C., K. Daly, and T.S. English (in press) Acoustic observations of biological volume scattering in the vicinity of the IXTOC-1 blowout. *Proceedings of the IXTOC-1 Symposium*, June 9-10, 1980, Miami, Florida.
- No. 1157
- Martin, S. (1980) Field study of brine drainage and oil entrainment in first-year sea ice. *Journal of Glaciology* 22: 473-502.
- No. 1114
- Martin, S. (in press) Anticipated oil-ice interactions in the Bering Sea. In Hood, D.W. (ed.), *The Eastern Bering Sea Shelf: Oceanography and Resources*.
- No. 1120

- Martin, S. (in press) Frazil ice in rivers and oceans. *Annual Review of Fluid Mechanics.*
- No. 1161
- Martin, S. and J. Bauer (in press) Bering Sea ice-edge phenomena. In Hood, D.W. (ed.), *The Eastern Bering Sea Shelf: Oceanography and Resources.*
- No. 1119
- Martin, S., P. Kauffman, and P.E. Welander (1979) A laboratory study of the dispersion of crude oil within sea ice growth in a wave field. In *Science in Alaska, 1976: Resource Development-Processes and Problems 2:* 261-287.
- No. 999
- McClain, J.S. and B.T.R. Lewis (1980) A seismic experiment at the axis of the East Pacific Rise. *Marine Geology* 35: 147-169.
- No. 1090
- McDaniel, N. and K. Banse (1979) A novel method of suspension feeding by the maldanid polychaete *Praxillura maculata* Moore. *Marine Biology* 55: 129-132.
- No. 1034
- McLean, S.R. and J.S. Smith (1979) Turbulence measurements in the boundary over a sand wave field. *Journal of Geophysical Research* 84: 7791-7807.
- No. 1044
- Merrill, R.T., M.W. McElhinny and D.J. Stevenson (1979) Evidence for long-term asymmetries in the earth's magnetic field and possible implications for dynamo theories. *Physics of the Earth and Planetary Interiors* 20: 75-82.
- No. 1109
- Minas, J.H., L.A. Codispoti, and R.C. Dugdale (in press) Nutrients and primary production in the northwest African upwelling region. *Rapports et Proces-Verbaux. Conseil International pour l'Exploration de la Mer.*
- No. 1035
- Murray, J.W. and J.G. Dillard (1979) The oxidation of cobalt (II) adsorbed on manganese dioxide. *Geochimica et Cosmochimica Acta* 43: 781-787.
- No. 1069
- Murray, J.W., S. Emerson, and R. Jahnke (1980) Carbonate saturation and the effect of pressure on the alkalinity of interstitial waters from the Guatemala Basin. *Geochimica et Cosmochimica Acta* 44: 963-792.
- No. 1150
- Murray, J.W. and V. Grundmanis (1980) Oxygen consumption in pelagic marine sediments. *Science* 209: 1527-1530.
- No. 1165
- Niedrauer, T.M. and S. Martin (1979) An experimental study of brine drainage and convection in young sea ice. *Journal of Geophysical Research* 84: 1176-1186.
- No. 1054

Nittrouer, C.A., R.W. Sternberg, R. Carpenter, and J.T. Bennett (1979) The use of Pb-210 geochronology as a sedimentological tool: Application to the Washington continental shelf. *Marine Geology* 31: 297-316.

No. 1046

Ozretich, R.J. (in press) Dissolved components of discharge. *Marine Mining*.  
No. 1178

Ozretich, R.J. (in press) Increased oxygen demand in micro-biomass. *Marine Mining*.

No. 1179

Pederson, A.M. and M.C. Gregg (1978) Development of a small in-situ conductivity instrument. In *Oceans 78 "The Ocean Challenge"*: 173-179. Fourth Annual Combined Conference 6-8 September 1978, Washington, D.C. The Marine Technological Society, Washington, D.C., and the Institute of Electrical and Electronics Engineers, New York, New York.

No. 1066

Perry, M.J. and R.W. Eppley (1981) Phosphate uptake by phytoplankton in the central North Pacific Ocean. *Deep-Sea Research* 28: 39-49.

No. 1173

Perry, M.J., M.C. Larsen, and R.S. Alberte (in press) Photoadaptation in marine phytoplankton: response to the photosynthetic unit. *Marine Biology*.

No. 1180

Prahl, F.G., J.T. Bennett, and R. Carpenter (1980) The early diagenesis of aliphatic hydrocarbons and organic matter in sedimentary particles from Dabob Bay, Washington. *Geochimica et Cosmochimica Acta* 44: 1967-1976.

No. 1170

Prahl, F.G. and R. Carpenter (1979) The role of zooplankton fecal pellets in the sedimentation of polynuclear aromatic hydrocarbons in Dabob Bay, Washington. *Geochimica et Cosmochimica Acta* 43: 1959-1972.

No. 1094

Rattray, M., Jr. (1980) Salt flux mixing in the Columbia River. *Estuarine and Coastal Marine Science* 10: 479-493.

No. 1126

Rattray, M., Jr. and J.G. Dworski (1980) Comparison of methods for analysis of the transverse and vertical circulation contributions to the longitudinal advective salt flux in estuaries. *Estuarine and Coastal Marine Science* 11: 515-536.

No. 1116

Rattray, M., Jr. and C.B. Officer (1979) Distribution of a non-conservative constituent in an estuary with application to the numerical simulation of dissolved silica in the San Francisco Bay. *Estuarine and Coastal Marine Science* 8: 489-494.

No. 1067

Rattray, M. Jr. and C.B. Officer (in press) Discussion of trace metals in the waters of a partially mixed estuary. *Estuarine and Coastal Marine Science*.

No. 1181

Roden, G.I. (1979) The depth variability of meridional gradients of temperature, salinity, and sound velocity in the western North Pacific. *Journal of Physical Oceanography* 9: 756-767.

No. 1065

Roden, G.I. (1980) On the subtropical frontal zone north of Hawaii during winter. *Journal of Physical Oceanography* 10: 342-362.

No. 1138

Roden, G.I. (1980) On the variability of surface temperature fronts in the western Pacific as detected by satellites. *Journal of Geophysical Research* 85: 2704-2710.

No. 1139

Roden, G.I. and T. Emilson (in press) Physical oceanography of the Gulf of California. *Proceedings of the Gulf of California Symposium*, November 1979, Mazatlan, Mexico.

No. 1123

Runge, J.A. (1980) Effects of hunger and season on the feeding behavior of *Calanus pacificus*. *Limnology and Oceanography* 25: 134-145.

No. 1098

Schoener, A. and C.H. Greene (1980) Variability among identical fouling panels in Puget Sound, Washington, U.S.A. In *Papers, Marine Biology*: 213-224. Fifth International Congress on Marine Corrosion and Fouling, 19-23 May, 1980, Barcelona, Spain.

No. 1108

Smethie, W.M. (1981) Vertical mixing rates in fjords determined using radon and salinity as tracers. *Estuarine and Coastal Marine Sciences* 12: 131-153.

No. 1169

Smethie, W.M. and M. Buchholz (1980) Close-spaced, large volume sampling of sharp gradients. *Deep-Sea Research* 27: 665-668.

No. 1141

Smethie, W.M. and W.R. Schell (in press) Vacuum extraction of natural levels of radon from seawater. *Marine Chemistry*.

No. 1105

Smith, G. and R.T. Merrill (1980) The origin of rotational remanent magnetization. *Geophysical Journal of the Royal Astronomical Society* 61: 329-336.

No. 1111

Smith, J.D. and D.M. Farmer (1980) Mixing induced by internal hydraulic disturbances in the vicinity of sills. In Freeland, H.J., D.M. Farmer and C.D. Levings (eds.), *Fjord Oceanography*: 251-257. *Proceedings of the*

NATO Conference on Fjord Oceanography, Victoria, British Columbia, June 4-8, 1979. Plenum Press, New York.

No. 1113

Swift, J.H., K. Aagaard and S.-A. Malmberg (1980) The contribution of the Denmark Strait overflow to the deep North Atlantic. *Deep-Sea Research* 27: 29-42.

No. 1121

Taft, B.A. and H.P. Freitag (1980) On the flow of the Kuroshio over the Izu Ridge. *The Kuroshio IV*: 181-200. Proceedings of the Fourth Symposium for the Cooperative Study of the Kuroshio and Adjacent Regions. Saikou Publishing Co., Ltd., Tokyo, Japan

No. 1068

Torgrimson, G.M. and B.M. Hickey (1979) Barotropic and baroclinic tides over the continental slope and shelf off Oregon. *Journal of Physical Oceanography* 9: 945-961.

No. 1096

Vidal, J. (1980) Physioecology of zooplankton. I. Effects of phytoplankton concentration, temperature, and body size on growth rate of *Calanus pacificus* and *Pseudocalanus* sp. *Marine Biology* 56: 111-134.

No. 1127

Vidal, J. (1980) Physioecology of zooplankton. II. Effects of phytoplankton concentration, temperature, and body size on the development and molting rates of *Calanus pacificus* and *Pseudocalanus* sp. *Marine Biology* 56: 135-146.

No. 1128

Vidal, J. (1980) Physioecology and zooplankton. III. Effects of phytoplankton concentration, temperature, and body size on the metabolic rate of *Calanus pacificus*. *Marine Biology* 56: 195-202.

No. 1129

Vidal, J. (1980) Physioecology of zooplankton. IV. Effects of phytoplankton concentration, temperature, and body size on the net production efficiency of *Calanus pacificus*. *Marine Biology* 56: 203-211.

No. 1130

Ward, B.B. and M.J. Perry (1980) Immunofluorescent assay for the marine ammonium-oxidizing bacterium *Nitrosococcus oceanus*. *Applied and Environmental Microbiology* April 1980: 913-918.

No. 1147

Wearn, R.B. and D.J. Baker, Jr. (1980) Bottom pressure measurements across the Antarctic Circumpolar Current and their relation to the wind. *Deep-Sea Research* 27: 875-888.

No. 1171

## INDEX TO CONTRIBUTORS TO CURRENT RESEARCH ACTIVITIES

- Aagaard, K., 33, 44  
 Ahmed, S.I., 6, 14, 15  
 Anderson, G.C., 1, 46  
 Apel, J.R., 37
- Baker, D.J., 31  
 Balistreri, L.S., 19  
 Banse, K., 2, 4, 5, 7, 10  
 Barrick, R., 16  
 Battisti, D., 39  
 Bauer, B.J., 30  
 Beck, J.R., 36, 40  
 Bennett, J.T., 17  
 Bock, C., 40  
 Booker, J.R., 24  
 Booth, B.C., 6  
 Bradt, J., 35  
 Brannon, E.L., 10  
 Bressler, S., 14  
 Bryan, W.B., 25  
 Burns, R.E., 45
- Carpenter, R., 16, 17  
 Chan, A.T.H., 46  
 Christensen, N.I., 25, 27  
 Clarke, A., 30, 39  
 Clayton, J.R., 6, 14  
 Coachman, L.K., 43, 44  
 Copping, A.A., 11, 12  
 Creager, J.S., 21  
 Criminale, W.O., 25  
 Crosson, R.S., 27
- Daly, K., 44, 47  
 Damkaer, D.M., 10  
 Darnall, C.H., 33, 43, 44  
 Davey, M.K., 29  
 Davis, E., 24  
 Delaney, J.R., 25, 26  
 Dey, D.B., 10  
 Donahue, J., 29  
 Dortch, Q., 6, 14, 36  
 Downing, J.P., 21  
 Dworski, J.G., 29, 31, 37, 41
- Eckman, J.E., 11  
 Emerson, S.R., 18, 19  
 English, T.S., 9, 43, 44, 47  
 Ertel, J., 20  
 Ewart, T.E., 38
- Frost, B.W., 3, 8, 9  
 Furlong, E.T., 16
- Gallagher, E.D., 12  
 Gardner, G., 40  
 Garmany, J., 25, 26  
 Garver, J., 6  
 Geier, S., 36, 40  
 Gelfenbaum, G., 21  
 Gibson, K., 24  
 Green, L.S., 47  
 Greene, C., 13  
 Gregg, M.C., 36  
 Grundmanis, V., 18
- Hall, M., 11  
 Halpern, D., 30  
 Hanzlick, D.J., 33  
 Harding, S., 32, 33  
 Hassett, R.P., 3  
 Hayes, S.P., 30  
 Hedges, J.I., 16, 20  
 Hegdahl, J.S., 25  
 Heron, G.A., 9, 10  
 Hickey, B.M., 36, 40  
 Holbrook, J., 37  
 Holloway, G., 29, 37  
 Holmes, M.L., 27  
 Huyer, J., 36
- Jacobs, L., 19  
 Jahnke, R.A., 19  
 Jamart, B., 4, 42  
 Johnson, H.P., 22, 23, 25, 26  
 Johnson, V., 15  
 Jumars, P.A., 4, 11, 12, 46
- Kalhorn, S., 18  
 Karsten, J., 25  
 Kauffman, P., 30  
 Kevorkian, J., 35  
 King, K., 10  
 King, S., 15  
 Kisker, D.S., 9  
 Kovala, P.E., 29  
 Krause, E.J., 31  
 Kristmannsson, S., 37  
 Kuivila, K., 18

- Landry, M., 3, 9  
 Larsen, L.H., 22, 29, 37, 47  
 Larsen, M.C., 1  
 Larson, N., 31, 36  
 Lee, H., 47  
 Lewin, J.C., 5, 6  
 Lewis, B.T.R., 25, 26, 27  
 Lindstrom, E., 32  
 Lister, C.R.B., 21, 24, 26  
 Liu, C.-T., 28  
 Long, C., 40  
 Lorenzen, C.J., 3, 11, 47  
 Macaulay, M.C., 47  
 Mann, D., 20  
 Martin, S., 30  
 Maykut, G.A., 30  
 McClain, K., 26  
 McCulloh, T.H., 27  
 McElhinney, M.W., 23  
 McManus, D.A., 21  
 McWilliams, J.C., 32  
 Merrill, R.T., 10, 22, 23  
 Miller, C.B., 8  
 Miller, H., 37  
 Mojesky, T., 24  
 Murray, J.W., 18, 19  
 Nowell, A.R.M., 11, 40, 41  
 Ohman, M., 9  
 Olsen, R.J., 2  
 Ota, A., 12  
 Ozretich, R.J., 45, 46  
 Ozturgut, E., 45  
 Pearson, C.E., 35, 42  
 Pederson, A.M., 31, 36  
 Perry, M.J., 1, 2  
 Peterson, G., 17  
 Pola, N., 36  
 Prahl, F.G., 16, 17  
 Quay, B., 18  
 Quinn, T., 10  
 Rattray, M., 31, 41  
 Reynolds, S., 38  
 Ripley, D., 35, 40  
 Roden, G.I., 35  
 Roetcisoender, D., 9  
 Roy, E., 21  
 Runge, J.A., 9  
 Sands, W.C., 47  
 Sanford, T.B., 34  
 Sawlan, J.J., 18  
 Sayles, M., 32  
 Schoener, A., 12, 13  
 Schumacher, J.D., 44  
 Self, R.F.L., 46  
 Shea, T., 36  
 Shen, C., 32  
 Sherwood, C., 21  
 Shetye, S.R., 31  
 Shi, N., 29  
 Smayda, T., 3  
 Smith, G., 23  
 Smith, J.D., 40, 41  
 Smith, R.L., 36  
 Smith, S.W., 26  
 Spooner, G.F., 33  
 Squire, V., 30  
 Stahl, L., 9  
 Sternberg, R.W., 21  
 Stewart, R.J., 21  
 Swif, J.H., 33  
 Tabor, J., 26  
 Taft, B.A., 29, 32  
 Taghon, G.L., 4, 11, 12  
 Thompson, G., 25, 27  
 Tripp, R.B., 33, 43, 44  
 Turin, H., 20  
 Tuthill, J., 25  
 Van Geen, A., 20  
 Wade, S., 26  
 Walline, P., 43  
 Ward, B.B., 2  
 Wearn, R.B., 31  
 Welander, P.L.R., 28  
 Welschmeyer, N., 1, 11  
 Werner, F., 40, 47  
 Winter, D.F., 4, 6, 42, 47  
 Wong, P., 25  
 Yen, J.D.Y., 9  
 Zakar, K., 3, 9

END

DATE  
FILMED

7 - 81

DTIC